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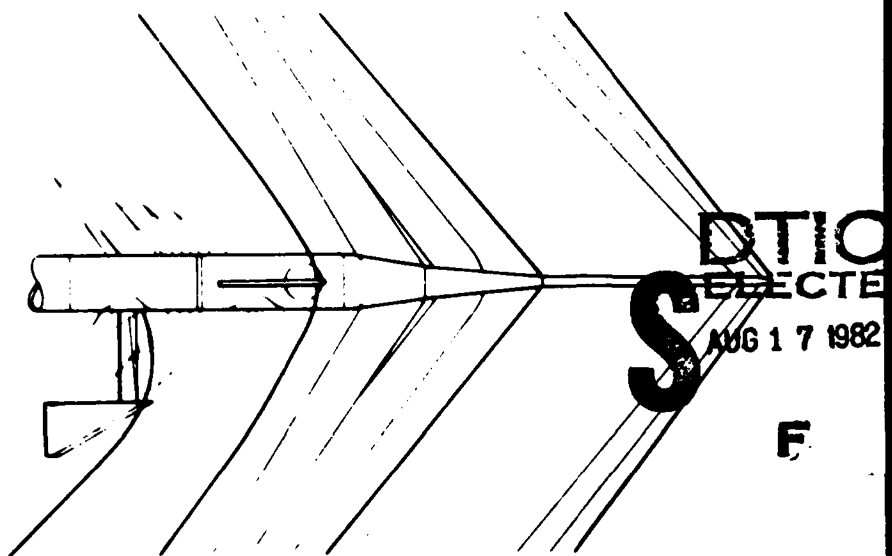
AERODYNAMIC CHARACTERISTICS OF THE AFFTC NOSEBOOM INSTRUMENTATION UNIT
VOLUME I OF II

KENNETH RAWLINGS III
MARK T. KORSMO

AFFTC

MARCH 1982



AIR FORCE FLIGHT TEST CENTER
EDWARDS AIR FORCE BASE, CALIFORNIA
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE

This Technical Information Memorandum (AFFTC-TIM-81-2), Aerodynamic Characteristics of the AFFTC Noseboom Instrumentation Unit, Volume I of II, was submitted under Job Order Number SC6342 by the Commander, 6520 Test Group, Edwards AFB, California 93523.

This report has been reviewed and cleared for open publication and/or public release by the AFFTC Office of Public Affairs in accordance with AFR 190-17 and DODD 5230.9. There is no objection to unlimited distribution of this report to the public at large, or by DDC to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public including foreign nationals.

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This technical information memorandum presents the results and data from wind tunnel calibration of the flow-angle sensing portion of the Air Force Flight Test Center noseboom instrumentation unit. Analysis of the data from the NASA/Ames Research Center 11- by 11-foot and 9- by 7-foot wind tunnels is presented along with fairings resulting from the analysis. The data fairings, which present error in sensed angle of attack and sensed angle of sideslip as a function of Mach number, angle of attack, and angle of sideslip, are

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20. summarized and compared extensively with the data. Computer software incorporating the data fairings in a concise form for data reduction routines and the software documentation are included. Volume I of this memorandum includes discussion of the analysis, data fairings, fairing-to-data comparisons, software and software documentation. Volume II is a run schedule and complete listing of the NASA/ARC original wind tunnel data.

PREFACE

Wind tunnel calibration of the Air Force Flight Test Center (AFFTC) noseboom instrumentation unit (NBIU) was undertaken as part of a joint USAF/NASA research program called the Transonic Aircraft Technology (TACT) program. The NBIU calibration was planned and supported by numerous individuals from NASA/Dryden Flight Research Center (NASA/DFRC) and NASA/Ames Research Center (NASA/ARC) as well as AFFTC. The test was conducted by personnel from NASA/ARC who obtained the data and applied normal wind tunnel corrections. Since the purpose of the calibration was TACT project support, no formal report was written, and data was transferred informally to project personnel from AFFTC and NASA/DFRC. The data was transmitted as "preliminary and subject to further checks" only because no formal coordination and checking was done and not because of any doubts about the data. The data was, in fact, very complete and highly coherent. Credit for the outstanding quality and coherence of the test data rests with Mr. James C. Daugherty and Lt Col (then Captain) Lowell Keel, USAF, of NASA/ARC who planned, ran, and applied corrections for the 11- by 11-foot and 9- by 7-foot wind tunnels respectively. Mr. Daugherty and Lt Col Keel were consulted numerous times during data analysis and intrepretation and their insight and guidance made the present analysis possible. The final fairings and interpretation, however, were generated solely by the authors and any errors or misinterpretation are their responsibility.

The analysis of the NASA/ARC data presented in this memorandum was undertaken to define a calibration of the AFFTC NBIU generally applicable for data reduction and analysis programs. The analysis was highly dependent on the consultation of Neil W. Matheny and Glenn M. Sakamoto of NASA/DFRC. Without the consultation and notes of Neil Matheny determination of pre- and post-test calibration procedures would have been impossible. Glenn Sakamoto's consultation, memos, and especially his previous analysis of the data contained in the referenced Technical Note were invaluable.

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LIST OF SYMBOLS AND ABBREVIATIONS

NOTE: Symbols in parenthesis are computer symbols

ITEM	DESCRIPTION	UNITS
	SYMBOLS	
ℓ (L)	characteristic length of body	ft
M	Mach number	N-D
R_e (RE)	Reynolds number	N-D
R_e/ℓ (RE/L)	unit Reynolds number	/foot
α	angle of attack	deg
β	angle of sideslip	deg
β_ε	compressibility parameter, $\beta_\varepsilon = \sqrt{1-M^2}$	N-D
Δ	prefix denoting a change in the parameter following	- -
	SUBSCRIPTS	
B	NBIU true value	- -
con	convergence	- -
LF	local flow	- -
V	NBIU vane indicated value	- -
0	zero	- -
	ABBREVIATIONS	
AEDC	Arnold Engineering Development Center	- -
AFFTC	Air Force Flight Test Center	- -
NASA/ARC	NASA/Ames Research Center	- -
NASA/DFRC	NASA/Dryden Flight Research Center	- -
NBIU	noseboom instrumentation unit	- -
TACT	Transonic Aircraft Technology Program	- -
VKF	Von Karman Gas Dynamics Facility	- -

INTRODUCTION

The Air Force Flight Test Center (AFFTC) noseboom instrumentation unit (NBIU) is a precision instrumentation package designed for quantitative performance flight testing. The NBIU consists of a pitot-static probe for sensing total and static pressure and a flow-angle/flight path accelerometer unit capable of sensing angle of attack, angle of sideslip, and an orthogonal set of accelerations in the vertical plane of the aircraft. There is an adapter between the pitot-static probe and the flow-angle sensor, and a transition section to connect the unit to a noseboom. Changes required to accomodate the two accelerometers within the flow-angle sensor housing cause the NBIU to differ significantly from NACA and other commonly used pitot-static/flow-angle sensing elements in size and shape. The external configuration of the NBIU, which is the result of numerous decisions and compromises made during the original development, has unique aerodynamic characteristics which have been defined by various wind tunnel tests. This report briefly summarizes the various configuration changes which took place during development and describes how the present configurations evolved. The background section traces the AFFTC NBIU development from its inception to the present configuration and describes the numerous wind tunnel tests which were used to evaluate the changes and to obtain calibrations.

The present calibration resulted from application of the AFFTC NBIU to a joint USAF/NASA research program known as the Transonic Aircraft Technology (TACT) Program. Participants in this program included NASA/Dryden Flight Research Center (NASA/DFRC), NASA/Ames Research Center (NASA/ARC), as well as AFFTC. As a part of this program, personnel from the three organizations conducted a wind tunnel calibration of a slightly modified AFFTC NBIU. The NBIU was tested at NASA/ARC to obtain as accurate and complete as possible calibration of the pitot-static probe and the flow-angle sensor. Although both the pitot-static and flow-angle sensor calibrations were obtained successfully, only the flow-angle sensor data and analysis are documented in this report.

Data from the NASA/ARC test was quality controlled, corrected for flow angularity, and transmitted in a preliminary form to AFFTC and NASA/DFRC for analysis. Data were analyzed to determine the relationship between indicated and true angle of attack and angle of sideslip. Prior to developing the NBIU calibration, the data were checked to ensure that the effects of wind tunnel flow angularity had been properly removed. The results of these checks and subsequent adjustments are presented to demonstrate the coherence of the data. Schlerin photographs were investigated to establish data ranges where reflected shocks might cause problems with data analysis. Correlation of these investigations with unexpected data results are noted as a means of explaining the results. The data which passed preliminary checks was used to develop a calibration of the NBIU as a flow-angle sensor. An acceptable calibration was obtained from Mach number of 0.4 to 2.5 across most of the usable angle-of-attack and angle-of-sideslip range. Reynold's number effects were investigated but none were found. The calibration which resulted from this analysis is presented as are measures of its accuracy and consistency. The calibration is compared with the angle-of-attack data in Appendix A and with the angle-of-sideslip data in Appendix B.

The calibration identifies significant differences between the indicated flow angles and the true ones. The differences in the angles arise from local flow around the NBIU itself and upwash of the noseboom used during the wind tunnel test. The primary source is local flow effects around the NBIU itself which include those due to interference, local separation, shock interaction with the flow field, and upwash/downwash of the NBIU itself. Since these effects vary with things such as screw protrusion, vane-to-vane alignment, vane roughness, manufacturing tolerances of components, and slight variations in NBIU configuration, they change little with various applications of the NBIU. Another error source present in the wind tunnel calibration is the upwash of the noseboom. Since this effect varies with each application, a method was developed to adjust the calibration to almost any other noseboom configuration. The method of applying the adjustment to the calibration is discussed in the report.

The calibration obtained from the NASA/ARC tests was programmed into a standard software package applicable to any project using the AFFTC NBIU. A programmer's guide and complete program listing is included in Appendix C. The calibration was obtained from data transmitted directly from NASA/ARC to AFFTC and NASA/DFRC. Because no other report containing this data was published, the entire data transmittal, with the exception of pitot-static parameters, is included in Volume II. This report and its appendices should give any user the ability to substantiate the calibration and apply it to most future projects.

BACKGROUND

Early investigations into the capabilities of flightpath-oriented accelerometer systems indicated the potential to significantly increase the ease and accuracy of obtaining performance data. To exploit this potential, the Air Force Flight Test Center (AFFTC) began in 1967 to procure hardware to demonstrate the advantages. The developed hardware was to become a standard piece of flight test instrumentation if the expected advantages were realized. The Development Branch with engineering support of the Performance and Flying Qualities Branch developed a specification for an instrumentation unit to be mounted on a standard flight-test noseboom. The proposed hardware would incorporate a pitot-static head, angle-of-attack and angle-of-sideslip sensors, as well as an orthogonal accelerometer set. In 1968, CONRAC Corporation was awarded a contract to design and fabricate a prototype of the integrated noseboom instrumentation unit (NBIU).

The design effort resulted in a simple configuration mounting the longitudinal and normal accelerometers on a single shaft with the angle-of attack vanes attached symmetrically on both sides of the shaft. Within limits dictated by the length of the accelerometers and the diameter of the NBIU housing, the angle-of-attack vanes were free to rotate and align with the flow past the noseboom. The indicated angle of attack of the noseboom was determined by measuring the angle that the vane deflected from the centerline. At the same time, the longitudinal accelerometer was aligned with the flow and the normal accelerometer maintained perpendicular to the flow. Mounting the accelerometers in this manner resulted in the section housing the angle-of-attack vanes and the accelerometers being considerably larger in diameter than previous noseboom units. To adapt the flow sensor section to a standard pitot-static head, a conical adapter section was used. Additionally, this original design mounted the angle-of-sideslip-sensor vane almost directly below the angle-of-attack vanes with the angle-of-sideslip vane 3 inches aft of the angle-of-attack vanes.

The configuration of the angle-of-attack shaft with the two accelerometers mounted on it resulted in a greatly increased moment of inertia of the angle-of-attack shaft. The low aspect ratio, flat plate vanes mounted on long cylindrical posts combined with the high shaft inertia lacked the aerodynamic/inertia characteristics to provide fast response and good damping. Thus, as a part of the design effort, a new vane design was incorporated for the angle-of-attack vanes and also used on the angle-of-sideslip vane for commonality. These vanes had a constant-chord planform with a 45 degree sweep angle, a high aspect ratio and a wedge cross section. In 1970, the new NBIU hardware was delivered to AFFTC for acceptance and development testing.

Part of the developmental testing was a calibration of the errors in indicated angle of attack and angle of sideslip to local flow around the NBIU. In July 1970, these tests began in the PWT-4T tunnel at the Arnold Engineering Development Center (AEDC). The tests were unsuccessful because of excessive vane oscillations caused by vane dynamic instabilities. Viscous dampers were added to the flow angularity sensing system and a successful calibration was obtained. The results of these tests are completely documented in Reference 1. Although the local flow errors were successfully obtained from the tests, the viscous dampers increased the response time to an intolerable level. The problem was brought to the attention of personnel from the Von Karman Gas Dynamics Facility (VKF) at the AEDC. Subsequently, an agreement was reached between AEDC and AFFTC that VKF would investigate the problem and attempt to solve it by changing the vane aerodynamic shape.

A thorough investigation by VKF indicated that it was possible to increase the stability of the vane system while obtaining acceptable response characteristics by redesign of the vanes. Two types of vanes were considered possible candidates: the first type was similar to the original design with greater sweep and lower aspect ratio and the second type was flat plate, delta planforms with cutoff tips. Two configurations of the first type and three configurations of the second were selected, manufactured, and mass balanced by VKF. A thorough description and discussion of selection criteria are contained in Reference 2. The final selection of a configuration was to be made based on dynamic stability tests run in Tunnel A at AEDC. The results of these tests, as documented in Reference 2, indicated that the delta planform vanes had superior damping characteristics. The one with the lowest time-to-half-amplitude and simplest support system was selected for further testing and has been used on all subsequent AFFTC NBIU's. The natural frequency and damping obtained from these tests are given in Figure 1.

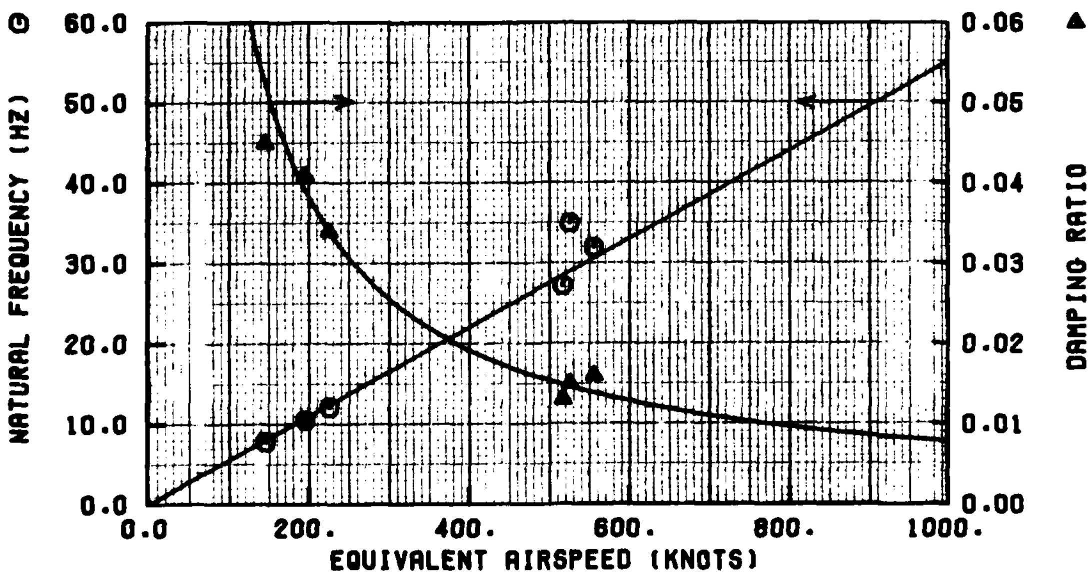
Once the vane design selection had been made, a complete local flow calibration was made from Mach numbers from 0.2 to 3.0 over a range of angles of attack, angles of sideslip, Reynolds numbers, and orientations. The results of these tests are documented in Reference 2. The tests indicated acceptable local flow errors in angle of attack over much of the Mach range, but unacceptably high errors in the transonic range, especially at Mach numbers of 1.1 to 1.3. Errors in angle of sideslip were acceptable over most of the range. The problem was attributed to shock/flow interaction caused by the close proximity of the sideslip vane to the angle-of-attack vanes and aggravated by the asymmetry caused by a single angle-of-sideslip vane. It was decided that more acceptable errors could be obtained if the angle-of-sideslip vane was moved aft. CONRAC was tasked with moving the angle-of-sideslip vane aft. Spacers were designed and fabricated to move it 6.28 and 12.28 inches aft. The spacer for 6.28 inches was tested first and found to be acceptable. After selection was made, a complete local flow calibration was made on the new NBIU configuration for the Mach range from 0.2 to 1.3. The results of this test are given in Reference 3.

The NBIU configuration which resulted from this test was determined to meet AFFTC requirements and the design was finalized. One of the prototype NBIU's was modified to the new configuration. Subsequent orders for 3 NBIU's by AFFTC were based on this design as were numerous other booms purchased by various aircraft contractors. The NBIU's of this design were used to support many programs from 1971 to 1981 including the A-10, F-15, B-1, and F-5.

AFFTC NBIU MODEL 2438-1 CALIBRATION
AEDC TUNNEL A - TEST VA0078 - 7 JUNE 1971
REFERENCE AEDC-TR-72-45 AND FTC-TIM-73-4

EQUIVALENT AIRSPEED (KNOTS)	MACH NUMBER	TOTAL PRESSURE (PSIA)	TOTAL TEMPERATURE (DEG R)	NATURAL FREQUENCY (HERTZ)	DAMPING RATIO	TIME TO HALF AMPLITUDE (SECONDS)
146.	0.31	8.1	560.	7.8	0.045	0.314
196.	0.51	6.0	560.	10.5	0.041	0.256
226.	0.71	4.8	560.	12.1	0.034	0.268
517.	3.00	36.6	560.	27.2	0.013	0.312
526.	1.50	15.3	560.	35.0	0.015	0.210
556.	2.50	28.7	560.	32.0	0.016	0.216

A)TABULATED DATA



B)PLOT AND FAIRINGS

FIGURE 1: NATURAL FREQUENCY AND DAMPING RATIO

The calibrations from the AEDC tests were reviewed and some analysis was done, but the results failed to become accepted for standard use in performance flight tests for several reasons. Probably the biggest reason was the limited documentation available for users. No AFFTC report was written and the AEDC reports presenting trends and basic analysis received limited distribution. The tabular, raw data received an even more restricted distribution. Lack of documentation and raw data prohibited resolution of apparent inconsistencies in the wind tunnel data. Many of the apparent inconsistencies arose from absence of corrections which the user must make during application of the data. Inconsistencies, coupled with lack of data to determine necessary corrections, severely lowered user confidence in the calibration. Another reason was the limited data available beyond a Mach number of 1.3. Tests on the final configuration were conducted only to a Mach number of 1.3, and the calibration relied on previous tests of other, slightly different, configurations to cover the Mach number range from 1.3 to 3.0. This further lowered user confidence and discouraged development of standard software implementing the calibration. As a result, the calibration had little or no use on operational flight test programs.

AFFTC and NASA/DFRC began preliminary planning in 1971 for the supercritical wing research program TACT. The accomplishment of a wind-tunnel-to-flight-test correlation required very accurate determination of angle of attack. To obtain a complete calibration of local flow corrections adequate to accomplish the program, it was decided to calibrate the AFFTC NBIU to be used and the TACT noseboom in a wind tunnel. NASA/ARC agreed to a very comprehensive series of tests planned by the three involved agencies. Prior to the tests, NASA/DFRC changed the pitot-static probe from a Rosemount Model 852V used on previous AFFTC NBIU's to a Rosemount Model 852G. This change was done to allow use of a probe more completely documented by NASA/DFRC. The change of pitot-static probe required a slight redesign of the transition adapter section between the probe and the flow angle/flight path acceleration sensor. The redesign involved changing from a uniform 6° slope to a 6° slope changing to a 9° slope and slightly lengthening the transition adapter. A comparison of the CONRAC and TACT adapter/pitot-static probes is shown in Figure 2. The redesigned adapter was manufactured by NASA/DFRC and installed on the NBIU. Additionally, they manufactured an "iron pipe" model of the TACT noseboom and shipped the unit to NASA/ARC. NASA/ARC performed test number 11/97-731 which consumed 140 hours of wind tunnel occupancy between 25 February and 12 March 1973. The data was transmitted to NASA/DFRC and AFFTC for determination of pitot-static and flow-angle calibrations.

The flow angle calibration data was initially analyzed by NASA/DFRC and documented in Reference 4. The report documented many details of the NASA/ARC tests and compared the AFFTC NBIU with previous NACA probes. The report presented an excellent qualitative analysis of local flow effects on the NBIU and clearly showed trends in the data. An AFFTC analysis was undertaken to expand the analysis presented in the NASA report, document the data taken, and develop standard software applicable to all AFFTC NBIU's used on flight test programs. The use of this software and adjustment based on an inflight calibration significantly improves accuracy over a total inflight calibration. The production software should be used on all flight test programs utilizing AFFTC NBIU's (Recommendation 1).

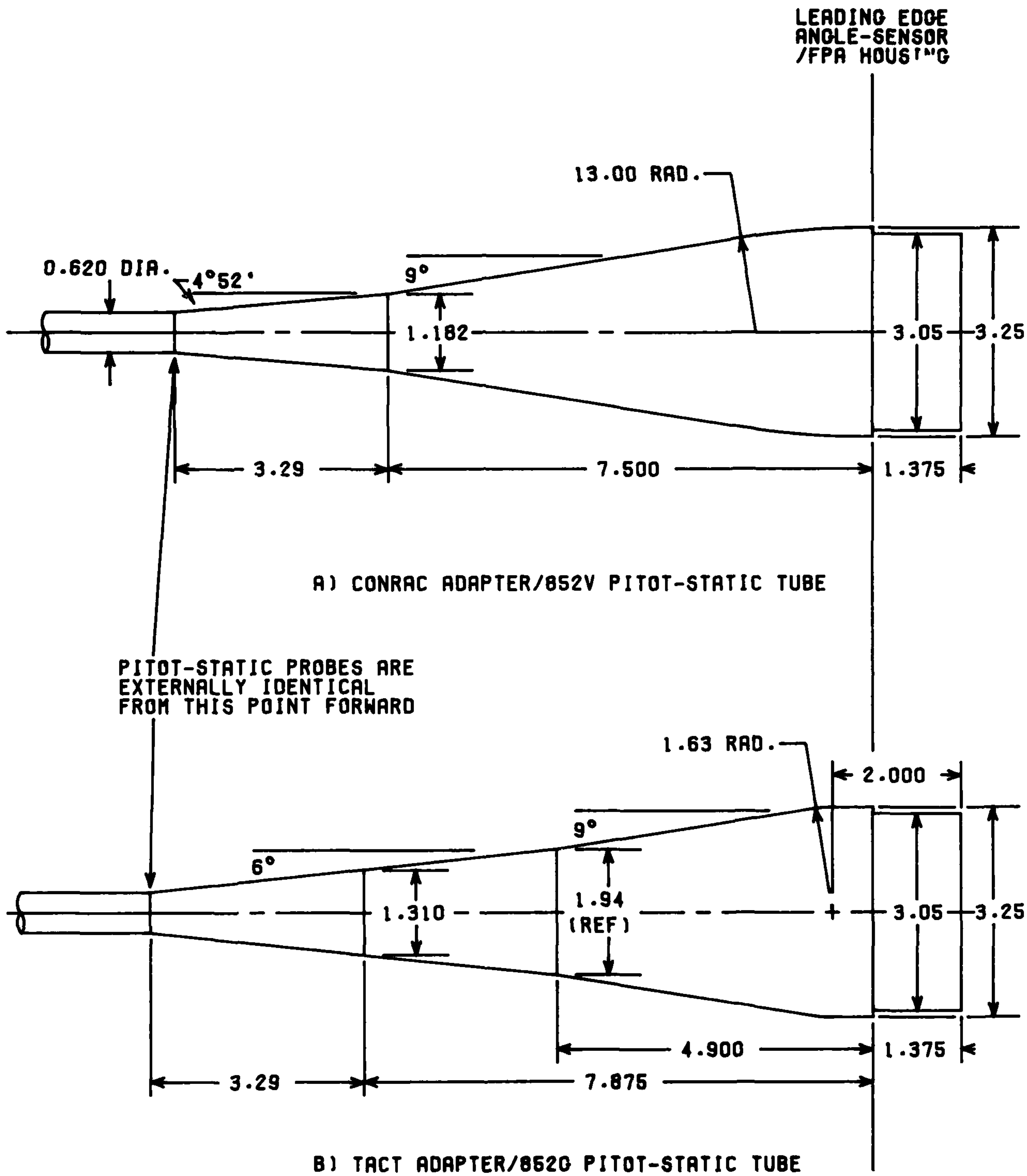


FIGURE 2: COMPARISON OF CONRAC AND TACT ADAPTER/PITOT-STATIC PROBES

TEST APPARATUS

The NBIU calibration conducted at NASA/ARC was done on a carefully selected and completely documented set of hardware. The NBIU supplied by AFFTC was one of the three prototype NBIU's built by CONRAC. It had been modified to the "production" status in terms of vane configuration and location. As described in the previous section, the pitot-static probe and pitot-static adapter had been changed to a later configuration. The noseboom supplied by NASA/DFRC was an "iron pipe" model of the TACT noseboom. Originally, it was formed from several independently machined segments and bolted together. During installation and check loading in the wind tunnel, it was noted that the boom had excessive deflection in several joints due to mechanical slop. To correct this, some of the joints were welded prior to any testing. The test hardware was completed by a sting mounting adapter supplied by NASA/ARC. The tunnel sting mounting system available in both NASA/ARC tunnels had combined movement in angle of attack and angle of sideslip of about 30 degrees and was symmetric about the tunnel centerline. NASA/ARC supplied an adapter to offset the plus or minus 15 degrees in angle of attack normally available by about 12.5 degrees. This allowed testing from -3 to +27 degrees in angle of attack as desired. Detailed descriptions of the tunnel sting mounting system and adapter were omitted because it was determined they had little or no influence on the flow around the NBIU.

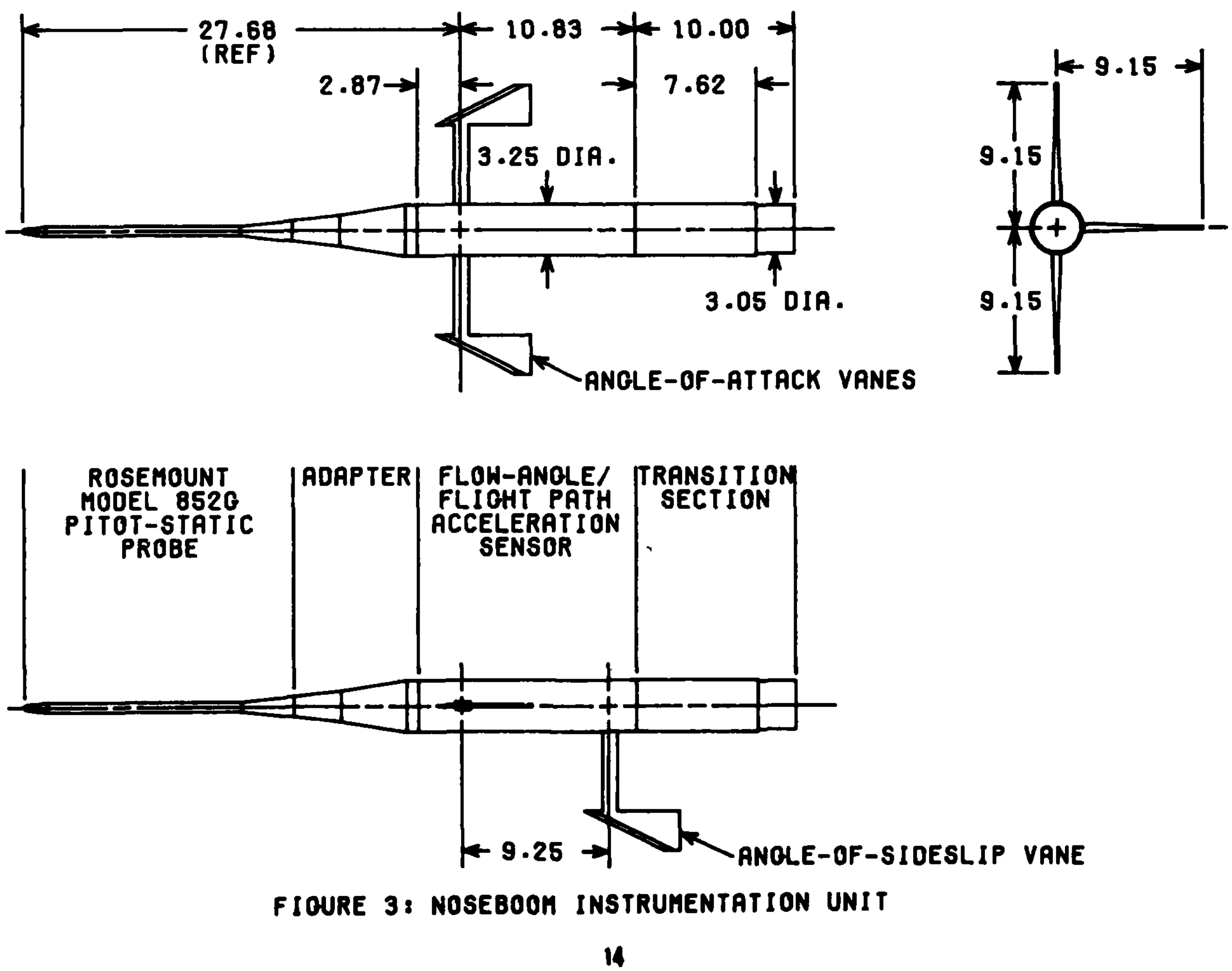


FIGURE 3: NOSEBOOM INSTRUMENTATION UNIT

The NBIU and noseboom used during the NASA/ARC test are described in detail below. Because this test is the best documented and most complete calibration of an AFFTC NBIU, the best accuracy and highest confidence in the calibration occurs when the TACT variant of the NBIU is used. Although the differences in the production NBIU and TACT configuration are minimal, some small effects of the change may occur. All new AFFTC NBIUs should be built in the TACT configuration, and all existing NBIU's should be modified when practical (Recommendation 2).

NBIU CONFIGURATION

The NBIU configuration is shown in Figure 3. The body of the angle-sensor/flight path accelerometer is a tube 3.25 inches in diameter which mounts two angle-of-attack sensing vanes on opposite ends of a lateral shaft and a single angle-of-sideslip sensing vane on the bottom. The vanes whose external details are shown in Figure 4 are the "production"

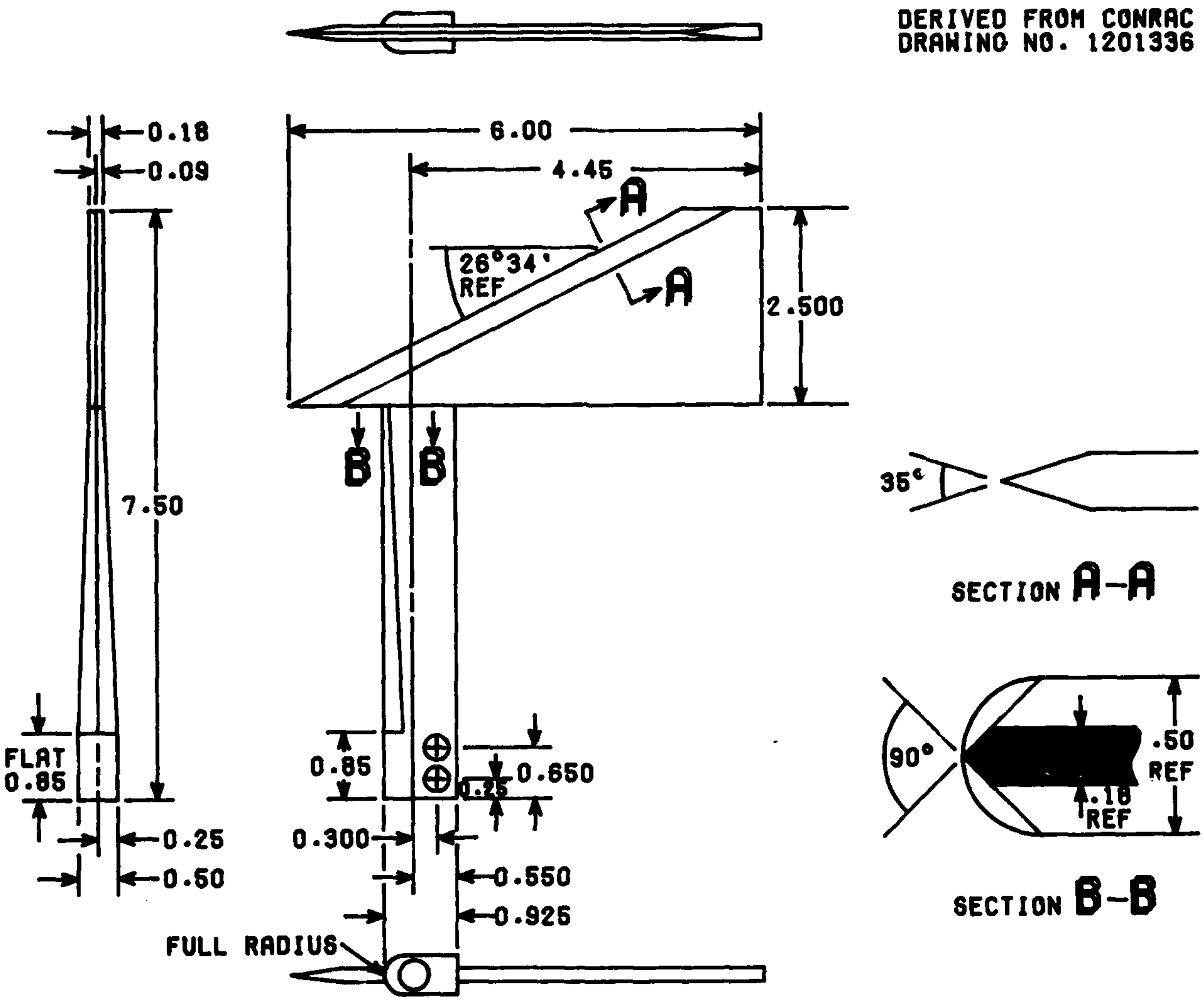


FIGURE 4: AFFTC NBIU FLOW-ANGLE-SENSOR VANE EXTERNAL DETAILS

vane configuration uses on all AFFTC NBIUs. Prior to testing, the vanes were cleaned, checked for nicks and scratches, and checked as well as possible for bending or warping. At the same time the two angle-of-attack vanes were checked for vane-to-vane alignment. Normally these vanes are aligned to each other and to the sensitive axis of the longitudinal accelerometer to within 10 arc seconds or .003 degrees. The checks of this unit both before and after the NASA/ARC tests showed vane-to-vane alignment to within only 0.05 degrees. The details of this misalignment which resulted during field repair of the NBIU are given in Figure 5. Although this misalignment is not within accepted standards, it was decided to leave the vanes as they were because 24 TACT flights had already been flown and calibration data were needed. It was determined during analysis of the calibration data that effects of the misalignment were clearly evident. It was felt, however, that the effect was confined to a small bias in the calibration which was easily removed. Thus, the misalignment did not materially affect the calibration or reduce confidence in the results.

	PRE-TEST* MISALIGNMENT CHECK	POST-TEST+ MISALIGNMENT CHECK
A MISALIGNMENT BETWEEN LEFT AND RIGHT ANGLE-OF-ATTACK VANES	0.0527 DEG	0.0508 DEG
B MISALIGNMENT BETWEEN EACH VANE AND AVERAGE VANE PLANE	0.0263 DEG	0.0254 DEG
C MISALIGNMENT BETWEEN AVERAGE VANE PLANE AND LONGITUDINAL ACCELEROMETER SENSITIVE AXIS	0.0426 DEG	0.0462 DEG

*PRE-TEST CHECK PERFORMED AT AFFTC LABORATORY AND NASA/DFRC

+POST-TEST CHECK PERFORMED AT NASA/DFRC

FIGURE 5: ANGLE-OF-ATTACK VANE MISALIGNMENT

The angle-of-attack vane shaft and angle-of-sideslip vane shaft ride internally on precision, low friction ball bearings which allow them to rotate freely and align with the local flow around the NBIU. The ro' ion of both shafts relative to the body of the NBIU are sensed with a syncn.o arrangement. The orthogonal set of accelerometers - one parallel to the angle-of-attack vanes and the other perpendicular - are a large assembly which limit the travel of the angle-of-attack vanes by contacting the bottom of the case or the pitot-static lines routed along the top of the section. The angle-of-attack vanes for this particular system were physically constrained to deflection from -3 degrees (vane trailing edge down, TED) to +28 degrees (vane trailing edge up, TEU) relative to the boom centerline. The negative limit was constrained slightly from its normal limit of approximately -5 degrees because the pitot-static lines were slightly shifted from their normal position. The angle of attack/accelerometer system represented a large mass which could affect sensed angle of attack if not mass balanced. During preliminary checks, the mass balance was checked and found to be within acceptable limits. The angle-of-sideslip vane was physically constrained to travel from -15 degrees (vane trailing edge right, TER) to +15 degrees (vane trailing edge left, TEL). The angle-of-sideslip vane is mass balanced at the factory and is not adjustable thereafter; a considerable out-of-balance condition was noted on the test NBIU.

The body is generally completed by a transition section to attach the NBIU to the noseboom. This section has access doors which allow the aircraft pitot-static lines to be disconnected from the NBIU so the NBIU can be removed from the noseboom. Although the transition section is required on the production NBIU's, it was not used on the TACT aircraft. Design of the prototype NBIU's, such as used on TACT, included access doors on the flow-angle-sensor housing. For development of a calibration applicable to all NBIU's, however, the transition section must be included. Therefore, the first 7.62 inches of the TACT noseboom were considered to be part of the NBIU for purposes of this calibration. Since the forward section of the noseboom had a 3.25 inch diameter, which is the same as the normal transition section, this gave exactly the same external configuration as a production NBIU and a foreshortened noseboom would have. This is strictly a "bookkeeping" exercise which can be ignored for purposes of working with the NASA/ARC data. It is very important, however, in determining noseboom lengths for making noseboom configuration corrections as discussed later.

NBIU PITOT-STATIC PROBE AND ADAPTER

The NBIU was equipped with a Rosemount 852G, uncompensated pitot-static probe. As shown in Figure 6, the probe has one total-pressure and two independent static-pressure sources. The probe is manufactured as a single piece with its forward 16.935 inches exposed and an additional 2.375 inch long, 1.312 inch diameter section designed to slide within the pitot-static adapter. The mating section had two groups of 3 equally spaced, self-locking nutplates. The adapter shown in Figure 7 has identical patterns of countersunk holes which matched the pitot-static probe. The adapter had a similar smaller section which slid within the NBIU body. When the unit was assembled, a considerable amount of roughness resulted from the holes and protruding screw heads at both junctions. Consideration was given to filling the voids with putty to reduce the surface roughness, but in general this is an impratical practice and the holes were left unfilled. It was felt that this would be more representative of typical NBIUs.

ROSEMOUNT ENGINEERING COMPANY
MODEL 852G PITOT-STATIC TUBE

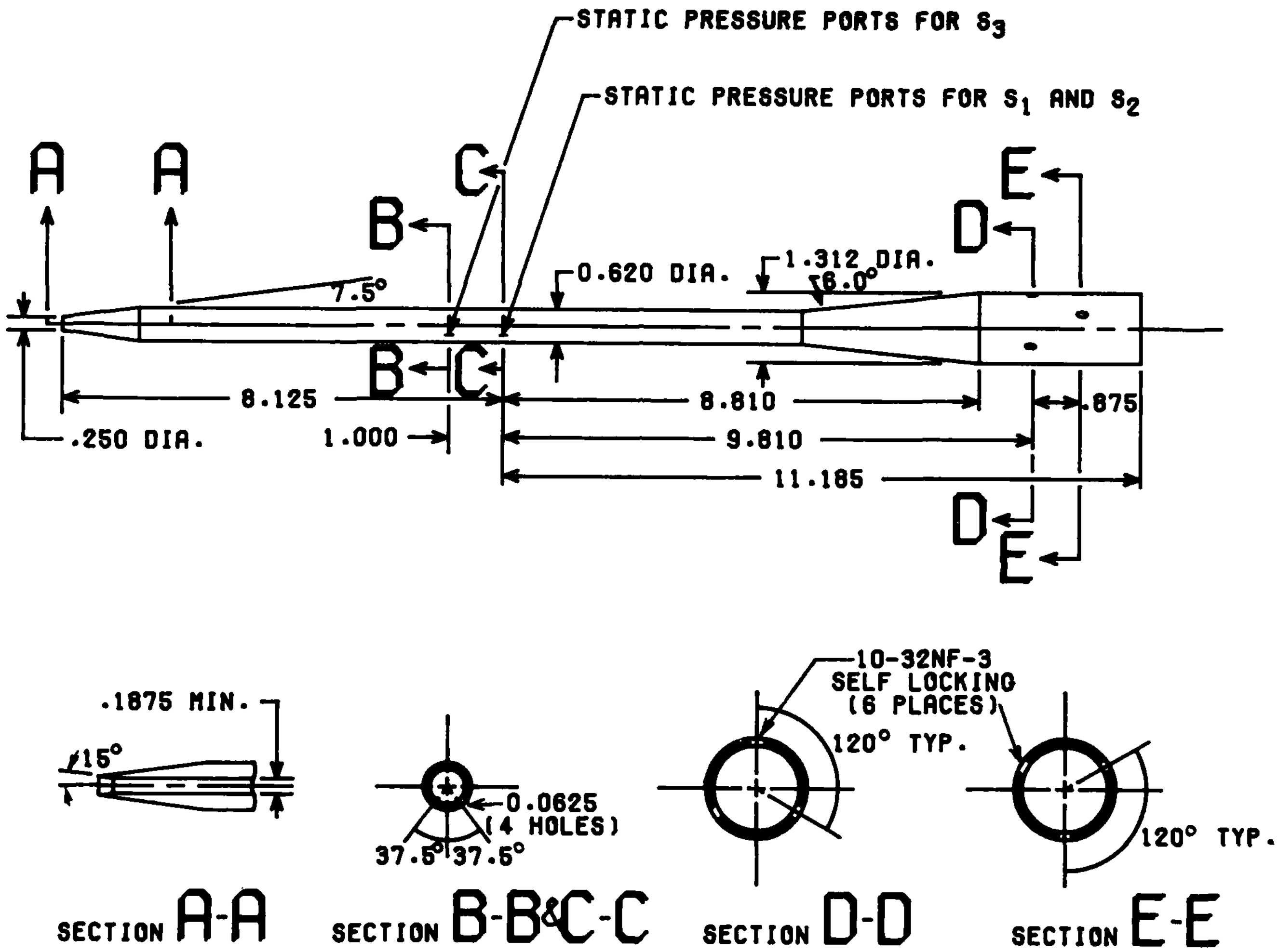


FIGURE 6: AFFTC NBIU PITOT-STATIC TUBE

DERIVED FROM AFFTC
DRAWING NO. X781233

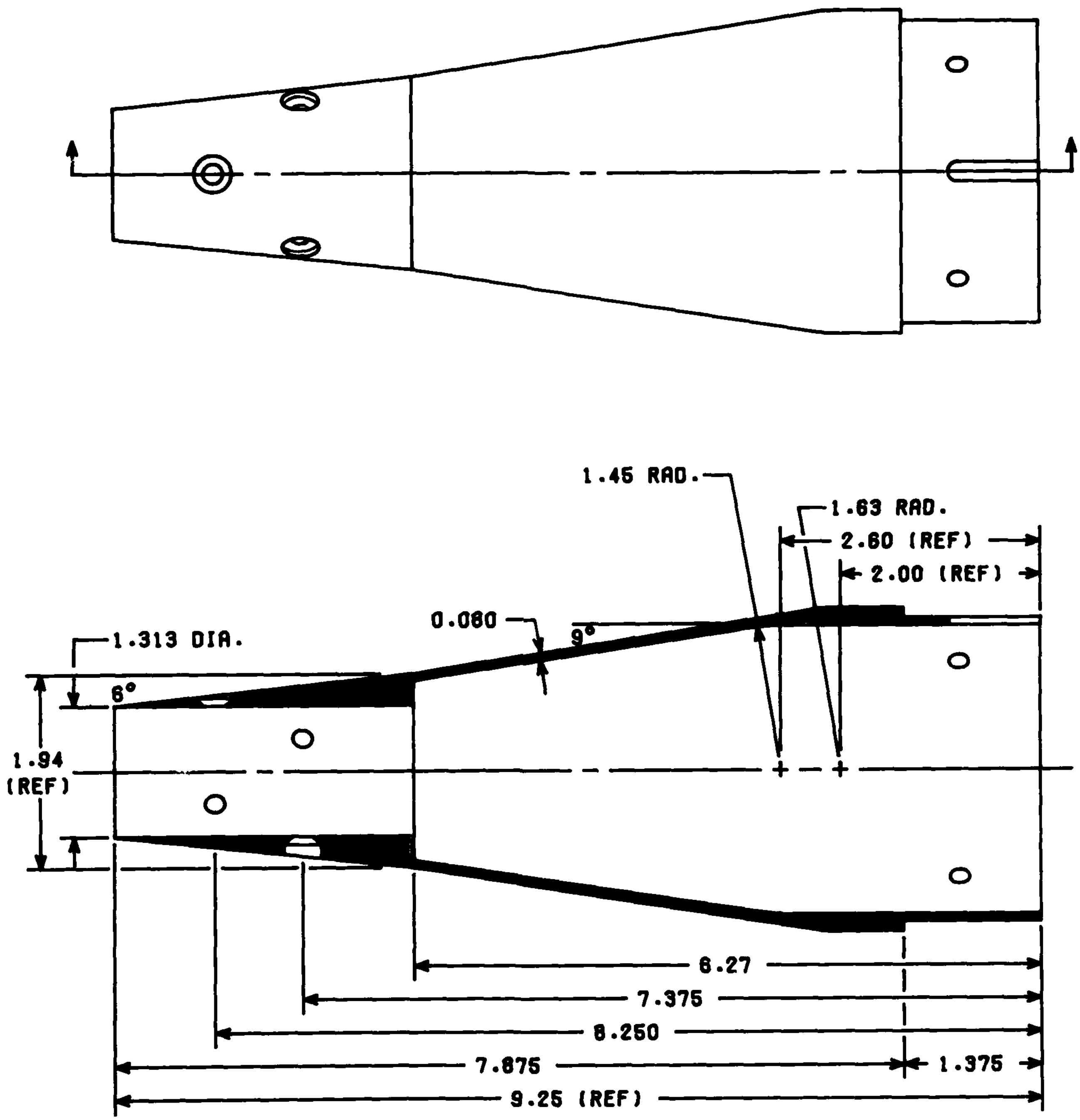


FIGURE 7: AFFTC NBIU PITOT-STATIC ADAPTER

WIND TUNNEL NOSEBOOM

The noseboom/NBIU installation for the wind tunnel is shown in Figure 8. This installation is the configuration on which the data analyzed in the following section was obtained. It is important to remember that this is a unique configuration and the calibration is applicable only to NBIU's mounted on this noseboom configuration. If a noseboom configuration other than that shown in Figure 8 is used, a correction must be made to the calibration to account for the differences as discussed in the Results section of this memorandum.

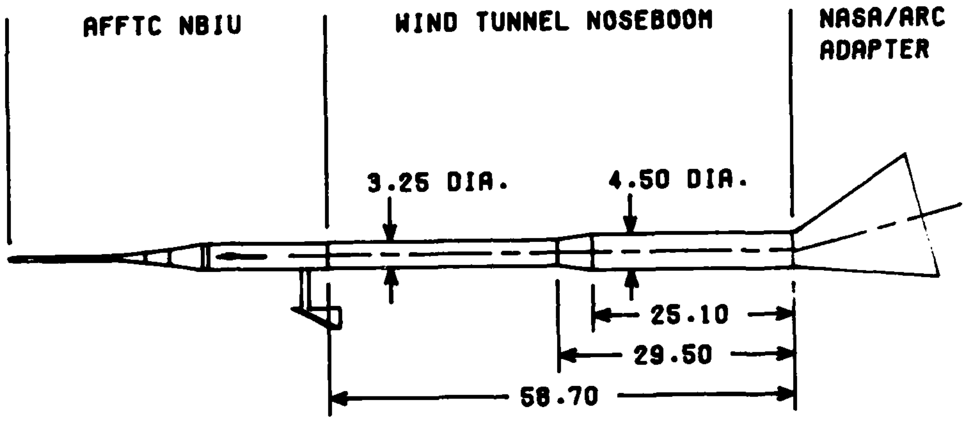


FIGURE 8: WIND TUNNEL NOSEBOOM CONFIGURATION

TEST EVALUATION

A thorough evaluation of the test conducted in the NASA/ARC wind tunnels was accomplished prior to data analysis. In conjunction with personnel from NASA/ARC and NASA/DFRC, the characteristics of the test facilities, test procedures, preliminary data corrections, and data characteristics were established. This was necessary to precisely define what corrections had been made and what further corrections were required during analysis of the preliminary data. Studies of facility characteristics established inherent limitations and resulted in an estimation of expected accuracies based on NASA/ARC experience with the test tunnels. Knowledge of the test facilities also aided in explaining inconsistent results which were noted in the transonic region. Studies of procedures used in preparing for and conducting the test established that with one small exception procedures were more than adequate. Study of the data transmitted to AFFTC and subsequently to NASA/DFRC established that all planned corrections had been made correctly. The evaluation proved that extreme care had been taken in preparing for and conducting the tests and correcting the data, and provided a high level of confidence in the results of the subsequent analysis.

TEST FACILITY

The NBIU tests were conducted in the Unitary Plan Wind Tunnel facility at NASA/ARC as described in References 5 and 6. Tests were conducted in both the 11- by 11-foot transonic wind tunnel and the 9- x 7-foot supersonic wind tunnel. Both tunnels were capable of operation over a range of precisely-controlled Mach numbers while stagnation pressure could be varied independently to facilitate studies at different Reynold's numbers and dynamic pressures. Both tunnels had model support hardware capable of precision-controlled movement in two orthogonal directions and roll about the noseboom centerline. Geometric orientation and position of the NBIU relative to the tunnel centerline was controlled and recorded on an automated data system. Concurrently, the indicated values of angle of attack, angle of sideslip, and pitot-static parameters from the NBIU were recorded. Schlieren photographs were made for flow visualization and analysis at most test conditions.

11- X 11-FOOT WIND TUNNEL:

The 11- by 11-foot wind tunnel is a closed-return, variable density tunnel with a fixed geometry, ventilated test section, and a nozzle comprised of flexible sidewalls, each actuated by a single jack. Airflow is produced by a three-stage, axial-flow compressor powered by four tandem, wound-rotor, variable-speed induction motors capable of generating a total of 180,000 horsepower continuously. The Mach number capability of this tunnel is 0.4 to 1.4. Variable density is achieved by varying stagnation pressure from 0.3 to 2.25 atmospheres.

The flexible sidewall nozzle of the 11- by 11-foot tunnel produces very uniform flow through the test section with very low flow angularity. Numerous calibrations over an extended period of time have shown typical values of flow angularity in the angle-of-attack direction to be less than 0.15 degrees and in the angle-of-sideslip direction to be less than 0.1 degrees. The model support system has movement of approximately 30 degrees in the normal pitch direction (wings level) and approximately 30 degrees in the normal yaw direction. For the NBIU calibration, NASA/ARC supplied an adapter to bias the pitch movement by about 12.5 degrees and allow testing from -3 to 27 degrees.

9- X 7-FOOT WIND TUNNEL:

The 9- by 7-foot wind tunnel is a closed-return, variable density tunnel equipped with an asymmetric, sliding-block nozzle and a flexible upper plate. Variation of the test section Mach number is achieved by translating, in a streamwise direction, a fixed contour block that forms the floor of the nozzle and test section. The electrical drive system is common to both the 11-foot tunnel and the 9- by 7-foot tunnel. The Mach number range of this tunnel is 1.5 to 2.5. Variable density is achieved by varying stagnation pressure from 0.3 to 2.0 atmospheres.

The asymmetric, sliding block nozzle of the 9- by 7-foot tunnel produces nonuniform flow through the test section with extremely large and variable flow angularity in the vertical plane. The large variation in the vertical plane, which can be as much as three to four degrees between floor and ceiling, was anticipated during tunnel design and the model support system was designed with its normal pitch direction in the horizontal plane. The model support system also maintains the model center of rotation on the lateral centerline of the tunnel so that change in angular orientation of the model in the normal angle-of-attack direction doesn't result in movement of the model from the tunnel centerline. For the NBIU test, the center of rotation was located at the centerline of the angle-of-attack vanes. Because the test article doesn't move within the test section, flow angularity in the angle-of-attack direction typically can be maintained below 0.05 degrees. Movement in the angle-of-sideslip direction, however, encounters changes in flow angularity on the order of 1.0 degree and must be carefully corrected. The model support system of the 9- by 7-foot tunnel has movement of approximately 30 degrees in the normal pitch direction (wings vertical) and approximately 30 degrees in yaw. Again the travel was biased to allow testing from -2 to 16 degrees.

TEST DATA

Data was obtained from the 11- by 11-foot and 9- by 7-foot tunnels across the range of useable Mach number and range of the model support system. At selected Mach numbers several Reynolds numbers were run to insure that Reynolds number effects were not present. In both tunnels extensive tests were run to define flow angularity corrections and obtain the most accurate results possible. Flow angularity data was obtained in both the normal pitch and yaw directions. A summary of the Mach numbers, Reynold's numbers, angles of attack, and angles of sideslip are presented in Table 1. The run schedule for each tunnel and a summary of the data concerning test conditions, angle of attack, and angle of sideslip are contained in Volume II of this memorandum.

TABLE 1: TEST VARIABLES

WIND TUNNEL	MACH NUMBER	UNIT REYNOLDS NUMBER (/FOOT)	α_B (DEGREES)	β_B (DEGREES)
11- X 11-FOOT	0.40	2.0×10^6	-2 TO 22	-2 TO 12
	0.60	2.6×10^6	-2 TO 22	-2 TO 12
	0.80	2.1×10^6	-2 TO 22	-2 TO 12
	0.90	2.0×10^6	-2 TO 22	-2 TO 12
		3.3×10^6	-2 TO 10	0
		5.5×10^6	-2 TO 10	0
	0.95	1.8×10^6	-2 TO 22	-2 TO 12
	1.05	2.8×10^6	-2 TO 22	-2 TO 12
	1.10	2.9×10^6	-2 TO 22	-2 TO 12
	1.20	3.1×10^6	-2 TO 22	-2 TO 12
	1.30	2.4×10^6	-2 TO 22	0
		3.7×10^6	-2 TO 22	-2 TO 12
	1.40	4.1×10^6	-2 TO 10	0
9- X 7-FOOT	1.51	2.0×10^6	-2 TO 16	0
		4.0×10^6	-2 TO 16	-2 TO 12
	1.71	3.7×10^6	-2 TO 10	0
	1.91	4.3×10^6	-2 TO 16	-2 TO 12
	2.11	4.2×10^6	-2 TO 16	-2 TO 12
	2.31	4.1×10^6	0 TO 16	10 TO 12
	2.41	3.7×10^6	-2 TO 10	0
	2.54	3.6×10^6	-2 TO 16	-2 TO 12

11- X 11-FOOT WIND TUNNEL:

Data were obtained in the 11- by 11-foot wind tunnel from Mach number of 0.40 to a Mach number of 1.40. At Mach number of 0.90, three unit Reynolds numbers were run and at Mach number of 1.30 two unit Reynolds numbers were run. At most Mach numbers data were obtained across the angle-of-attack and angle-of-sideslip range. Primary method of obtaining data was to accurately establish angle of attack at some value between -2 and 22 in 2 degree increments and sweep angle of sideslip in 2 degree increments between -2 and 12 degrees.

9- X 7-FOOT WIND TUNNEL:

Data were obtained in the 9- by 7-foot wind tunnel from Mach number of 1.51 to 2.54. At a Mach number of 1.51, two unit Reynolds numbers were run. At most Mach numbers data were obtained across the angle-of-attack and angle-of-sideslip range. Again the primary method of obtaining data was to accurately establish angle of attack at some value between -2 and 16 degrees in 2 degree increments and sweep angle of sideslip in 2 degree increments between -2 and 12 degrees.

DATA ACCURACY

Accuracy of the calibration data was of primary importance in conducting the wind tunnel tests. Care was taken to consider any correction which might have a significant effect on accuracy and to make those corrections which were important. Procedures used in preparing for and conducting the tests were examined to insure they were adequate and correctly made. The tests were well documented in engineer's notes and an extensive review indicated a good job had been done in achieving accurate results. An assessment was made of the test accuracy and it was concluded the acceptable accuracy had been achieved.

TEST NBIU:

The test NBIU was examined to insure that it was in good condition and that it was representative of the configuration of the AFFTC NBIU. The examination included checks of the physical configuration for damage and misadjustment as well as checks of the transducers and calibrations.

Mass Balance. The angle-of-attack/flight-path acceleration assembly consisting of the angle-of-attack vanes and accelerometers is normally mass-balanced to avoid vane misalignment due to accelerations. A moveable mass is provided to allow adjustment of the mass balance. Although the problem is not as pronounced as in flight, mass balance problems do affect wind tunnel data because of varying gravitational component as angle of attack is varied. To preclude errors in the data due to out-of-balance condition, the NBIU was checked prior to shipment to NASA/ARC and found to be within limits. Similar checks were made of the mass balance of the angle-of-sideslip vane assembly. Although the assembly was found to be considerably out of balance, the work and delays required to correct the balance were not considered necessary to obtaining an acceptable calibration.

Vane Condition. The angle-of-attack and angle-of-sideslip vanes were examined and found to be in very good shape; no nicks, bending, or warping were noted which would affect the calibration.

Vane Alignment. Prior to use and periodically throughout flight test programs, the alignment of the vanes is checked to assure that the left and right vanes are aligned with each other and with the sensitive axis of the longitudinal accelerometer. Accepted standard for use at AFFTC is alignment within 10 arc seconds or .003 degrees. Checks of the test unit, however, showed vane-to-vane alignment to within only 0.05 degrees. The details are given in Figure 5. Investigation of the misalignment and its effect on the quality of the calibration was done. The investigation revealed that all indicated angle-of-attack values taken by NASA/DFRC were based on readings halfway between the left and right vane and that all corrections were done correctly and consistently as shown by a comparison of the pre- and post-test measurements. The misalignment was not, evidently, communicated to NASA/ARC personnel calibrating the angle-of-attack vane indicated values.

The calibration of the angle-of-attack vane synchro transmitter was described in reference 4. "A split-bubble clinometer accurate to 6 seconds was mounted on the boom and simultaneous readings were taken from it and the vane synchro transmitter. A bubble level accurate to 3 seconds was affixed to the angle-of-attack vane to indicate the level vane condition." Since the two vane system would respond like a vane(s) halfway between the two vanes, a bias of approximately 0.025 degrees was introduced into the indicated angle-of-attack values. The sign of the bias was dependent on which vane the bubble level was placed. The effects on the calibration data are discussed in a later section.

TEST NOSEBOOM:

The noseboom used in the NASA/ARC test was an "iron-pipe" model of the actual TACT noseboom. During final check loading, approximately 100 pounds was applied in the positive lift direction with negligible deflection in either the boom or model support system. No loads were applied in a lateral direction.

MODEL SUPPORT SYSTEM:

The model support system was instrumented to provide "geometric" true angle of attack and true angle of sideslip. The geometric values were relative to the tunnel centerline and would be the true values if there were no stream flow angle. These values, when corrected for flow angularity, were used as true angle of attack and true angle of sideslip. The drive unit was calibrated using a laser mounted on the noseboom and directed toward a fixed target upstream of the test section. Hysteresis was detected in the drive unit and was minimized by always approaching the angle of attack set in the tunnel from a higher angle of attack when taking test data.

TRUE FREESTREAM MACH NUMBER:

The freestream Mach number was obtained from standard wind tunnel calibrations run by NASA/ARC as described in reference 6.

11- By 11-Foot Wind Tunnel. The Mach number calibration of the 11- by 11-foot wind tunnel is based on measurement of stagnation pressure by a pitot probe located in the stilling chamber and on measurement of static pressure along the tunnel centerline. The static pressure measurements were accomplished by means of a long, two inch diameter pipe, mounted under tensile load along the tunnel centerline, running from the stilling chamber to the strut support system located downstream of the test section. Orifices located at twelve inch intervals along the pipe sense the "clear-tunnel" static pressure. (A second pipe with twelve inch orifice spacing, strut mounted 18 inches off the floor during subsonic calibration, essentially verified the centerline measurements.) Calculations based on the measured values of stagnation and static pressure provide calibration of clear-tunnel Mach number.

9- By 7-Foot Wind Tunnel. The Mach number calibration of the 9- by 7-foot wind tunnel is based on measurement of stagnation pressure by a pitot probe located in the stilling chamber and on measurement of total pressures every inch along the tunnel centerline. Such measurements were made by translating a small cone of about one-half inch diameter with a ten degree half angle along with tunnel centerline by means of a rack-and-pinion-drive support system. The nose of the cone was blunted to form a small-diameter, sharp-edged, total-head orifice. Calculations based on the measured values of stagnation pressure in the stilling chamber and total pressures along the tunnel centerline provided calibration of clear-tunnel Mach number.

These calibrations were used to obtain the freestream Mach number used in data analysis.

FLOW ANGULARITY CORRECTION:

The data were required to be corrected for flow angularity in the wind tunnel test section to obtain most accurate results. The flow angularity correction is defined as the correction to be applied to the model support hardware readings to obtain identical true angles at the same indicated angle from the NBIU whether it is in upright or inverted roll orientation. Since the indicated values are not affected by orientation, differences in true values at the same indicated values must be due to errors in true angles as determined geometrically from the model mounting system. The flow angularity corrections are adjusted until the same true values are obtained at the same indicated value both upright and inverted. The same reasoning is applicable to both angle-of-attack and angle-of-sideslip computations. The flow angularity correction is discussed more thoroughly in Appendix A of Volume II.

NASA/ARC routinely makes flow angularity corrections to data to increase the accuracy of the results. Typically, the values for the stream-angle correction to angle of attack were less than 0.15 degrees for the 11- by 11-foot wind tunnel and less than 0.05 degrees for the 9- by 7-foot wind tunnel. Lateral stream angle may be significant, especially in the 9- by 7-foot wind tunnel. The nozzle of the 11- by 11-foot wind tunnel provides relatively uniform flow which experience has shown has lateral flow angle of less than 0.1 degrees. The flow in the test section of the 9- by 7-foot wind tunnel, however, is established by an asymmetric, sliding-block nozzle which results in significant flow angularities; the flow angle correction can be on the order of 1 degree. The NBIU calibration data was corrected for flow angularity prior to transmission to AFFTC and checks of the corrections indicated that the data had been adequately corrected. The details of the checks prior to use are discussed in the Data Analysis section.

OVERALL SYSTEM ACCURACY:

An assessment was made of the overall system accuracy so that s quantitative estimate could be made of how good the NBIU was in sensing angle of attack and angle of sideslip. The assessment was based on analysis of procedures, other published results, and analysis of the test data. The conclusion was that table 2, which was obtained from reference 4, adequately summarizes expected accuracy for Mach number, angle of attack, and angle of sideslip. The accuracies in true angle of attack and true angle of sideslip depend on adequate correction for flow angularity. The flow angularity correction for angle of attack was based on data from minus three degrees to plus three degrees at zero angle of sideslip and the angle of sideslip correction was obtained across the obtainable range of angle of sideslip but only at zero angle of attack. There is a possibility that the accuracy was somewhat degraded outside these limits. Although experience with the tunnels would indicate the degradation was small, no effort was made to quantify the degradation in accuracy of this data.

TABLE 2: ESTIMATED ACCURACY OF NASA/ARC TEST VARIABLES

WIND TUNNEL	ESTIMATED ACCURACY OF					
	NBIU TRUE VALUES			NBIU INDICATED VALUES		VANE ERROR
	MACH NUMBER	α_B (DEGREES)	β_B (DEGREES)	α_V (DEGREES)	β_V (DEGREES)	$\Delta\alpha_{LF}$ (DEGREES)
11- X 11-FOOT	±0.005	±0.01	±0.15	±0.05	±0.05	±0.05
9- X 7-FOOT	+.08,-0.*	±0.05	±0.05	±0.05	±0.05	±0.07

*THESE VALUES BASED ON LATER DATA THAN REFERENCE 4.

DATA ANALYSIS

The data from the NASA/ARC test was extensively analyzed and used to develop a calibration of the AFFTC NBIU. The boom true angle of attack, α_B, and true angle of sideslip, β_B, used in the analysis were values obtained from the model support hardware corrected for flow angularity. The indicated or "vane" values of angle of attack, α_V, and angle of sideslip, β_V, were obtained from the deflection of the vanes indicated by the angle-sensor portion of the NBIU. The indicated value of angle of attack is normally defined as the deflection of the left vane from the horizontal plane of the NBIU. On this test, however, the vane-to-vane misalignment between the left and right vane was so large that the indicated value was defined as the deflection of the average vane (the average of the left and right vane deflection) from the horizontal plane. The indicated value of the angle of sideslip was the deflection of the vane from the vertical plane. The data were corrected for errors discovered during preliminary evaluation of the data and faired. The data fairings were programmed into a software package applicable as an "instrument calibration" for the flow-angle-sensing portion of the AFFTC NBIU. The data were primarily presented in terms of a local flow correction for angle of attack, $\Delta\alpha_{LF}$, and for angle of sideslip, $\Delta\beta_{LF}$, as defined in equations (1) and (2).

$$\Delta\alpha_{LF} = \alpha_B - \alpha_V \quad (1)$$

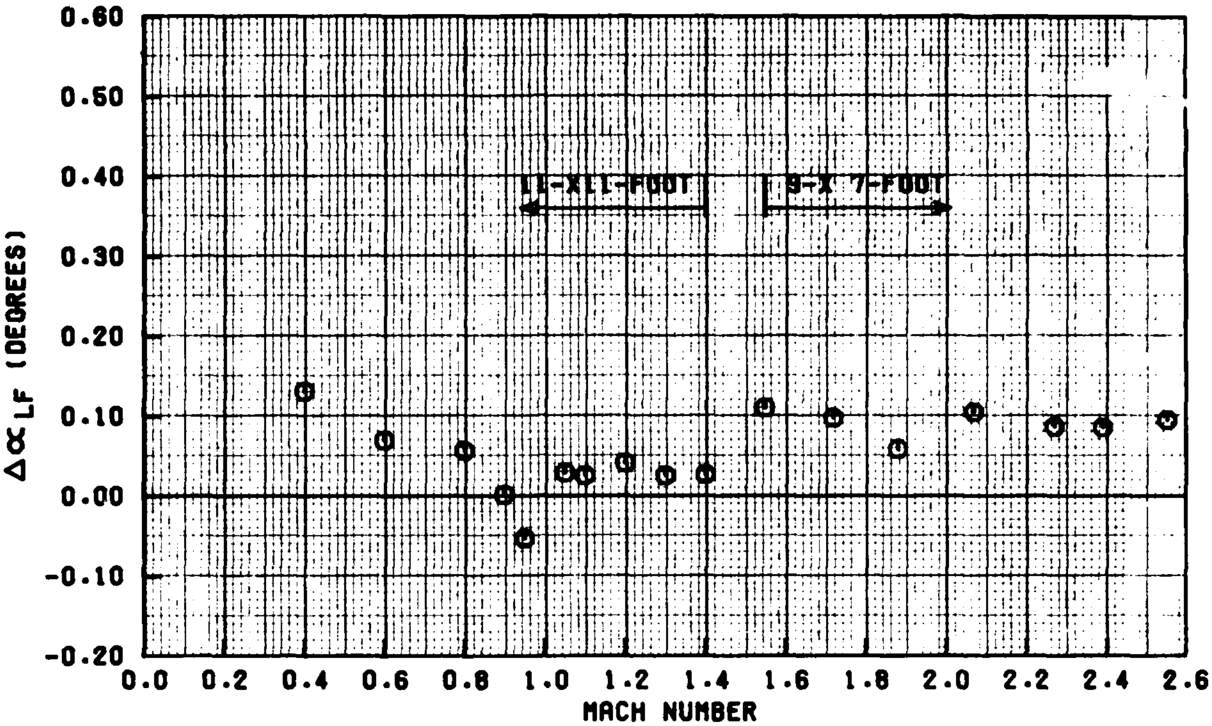
$$\Delta\beta_{LF} = \beta_B - \beta_V \quad (2)$$

DATA CORRECTIONS

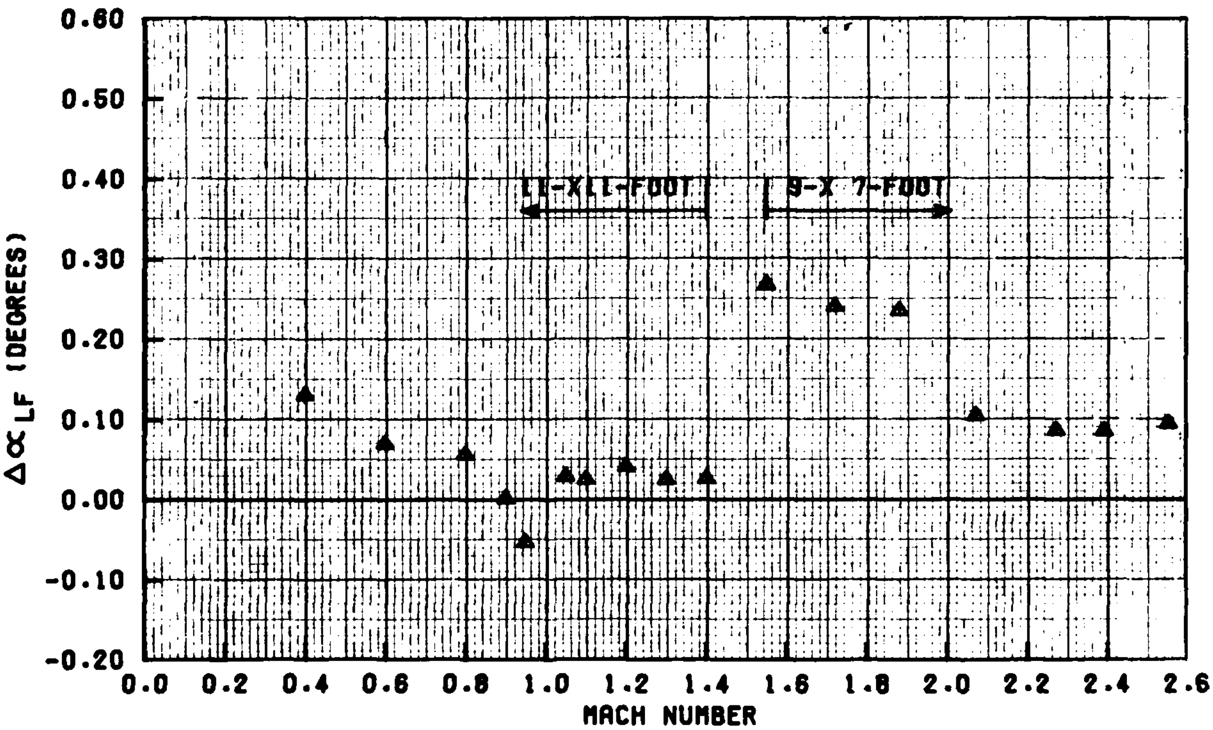
Preliminary evaluation of the NASA/ARC data indicated a very consistent set of data with few problems. The problems which did exist, however, were significant to the data analysis and had potential impact of the accuracy of the data and the confidence which personnel would have in the resultant calibration. The checks for flow angularity revealed no significant problems with the flow angularity corrections. The same checks, however, revealed biases in the data. Lastly, a large spike in the data was detected in the transonic region. The resolution of these problems resulted in corrections to the data which greatly enhanced the consistency of the data and gave reason for increased confidence in the results.

FLOW ANGULARITY:

The data were initially checked for flow angularity to insure that the corrections had been made by NASA/ARC. The plots shown in figure 9 were generated from the original data as described in Appendix A of Volume II and show the flow angularity check on angle of attack. The plots of upright configuration shown in figure 9(a), of inverted configuration in figure 9(b), and of combined configurations in figure 9(c) indicated that the angle-of-attack data had been effectively corrected for flow angularity.

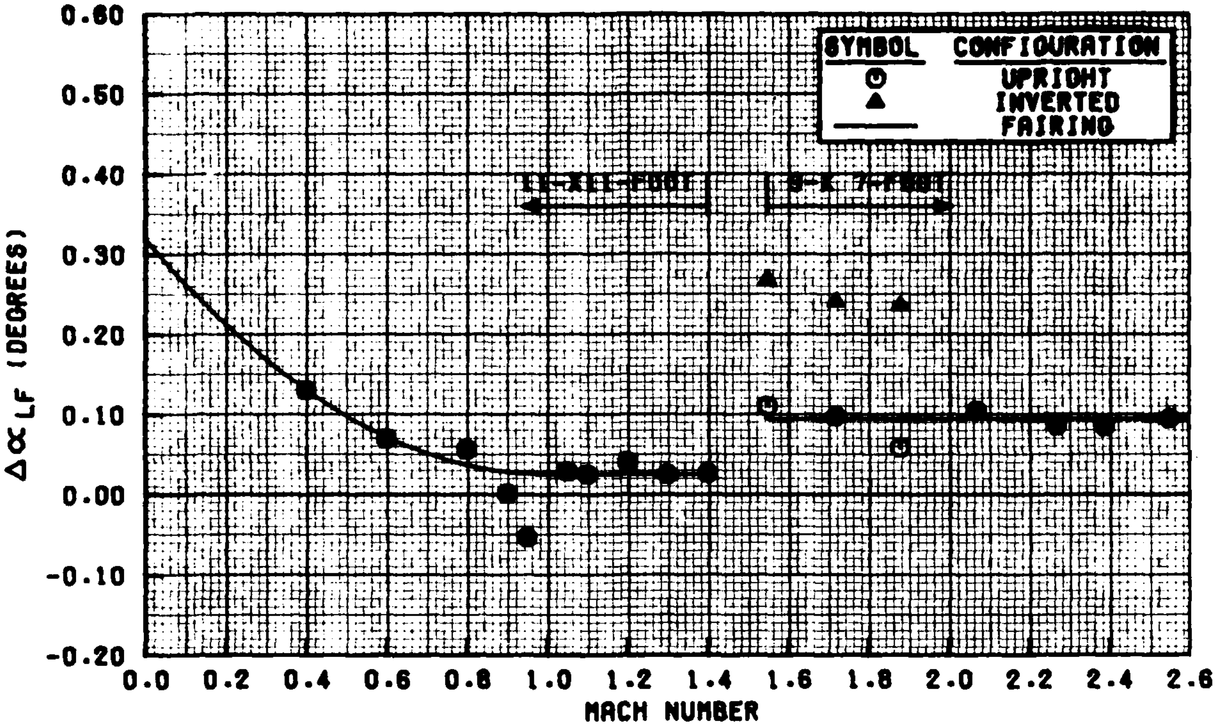


A) UPRIGHT CONFIGURATION, TRUE ANGLE OF ATTACK = 0.0 (DEGREES)



B) INVERTED CONFIGURATION, TRUE ANGLE OF ATTACK = 0.0 (DEGREES)

FIGURE 9: FLOW-ANGULARITY CHECK OF ORIGINAL ANGLE-OF-ATTACK DATA

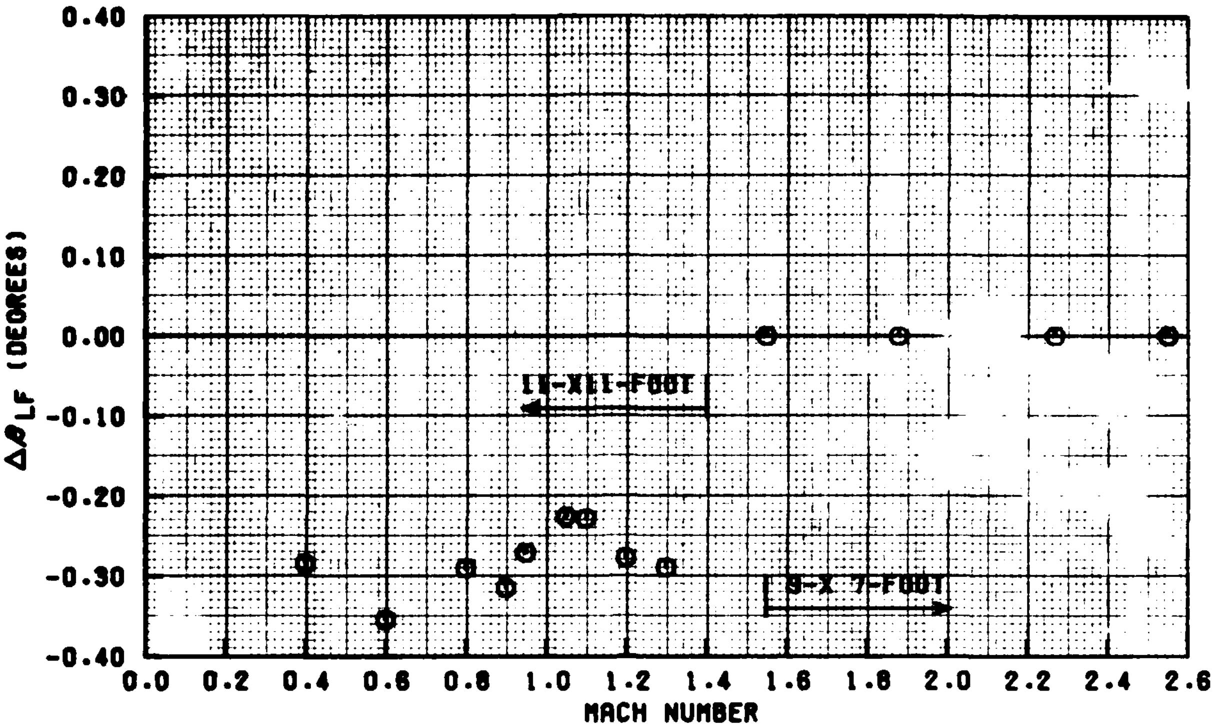


C) COMBINED CONFIGURATIONS, TRUE ANGLE OF ATTACK = 0.0 (DEGREES)

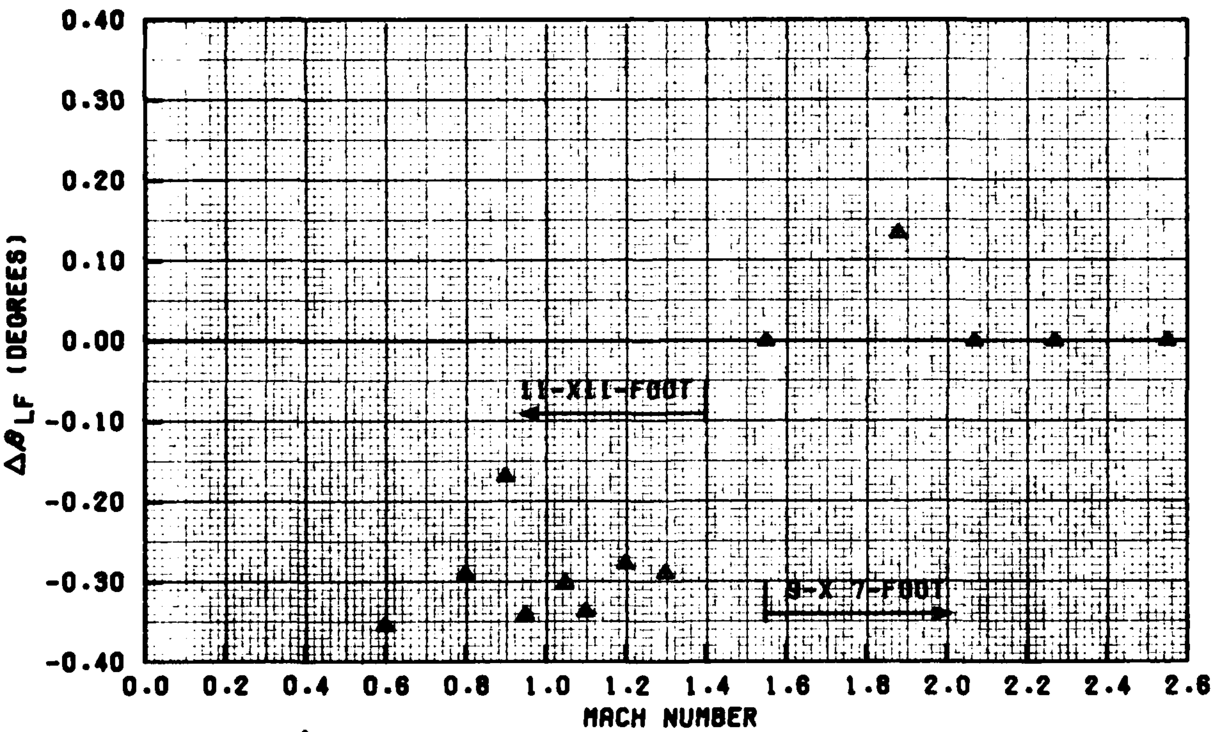
FIGURE 9: FLOW-ANGULARITY CHECK OF ORIGINAL ANGLE-OF-ATTACK DATA (CONCLUDED)

Similar plots showing the flow angularity check on angle of sideslip had similar results when checks of the original data were plotted. The plots of upright configuration shown in figure 10(a), of inverted configuration in figure 10(b), and of combined configuration in figure 10(c) indicated that the angle-of-sideslip data had been effectively corrected for flow angularity.

The flow angularity checks as described in Appendix A of Volume II identified several data runs which were inconsistent with the mass of data. Although no reason could be established for their inconsistency, they were removed from further analysis. Figures 11 and 12 following have these points removed.

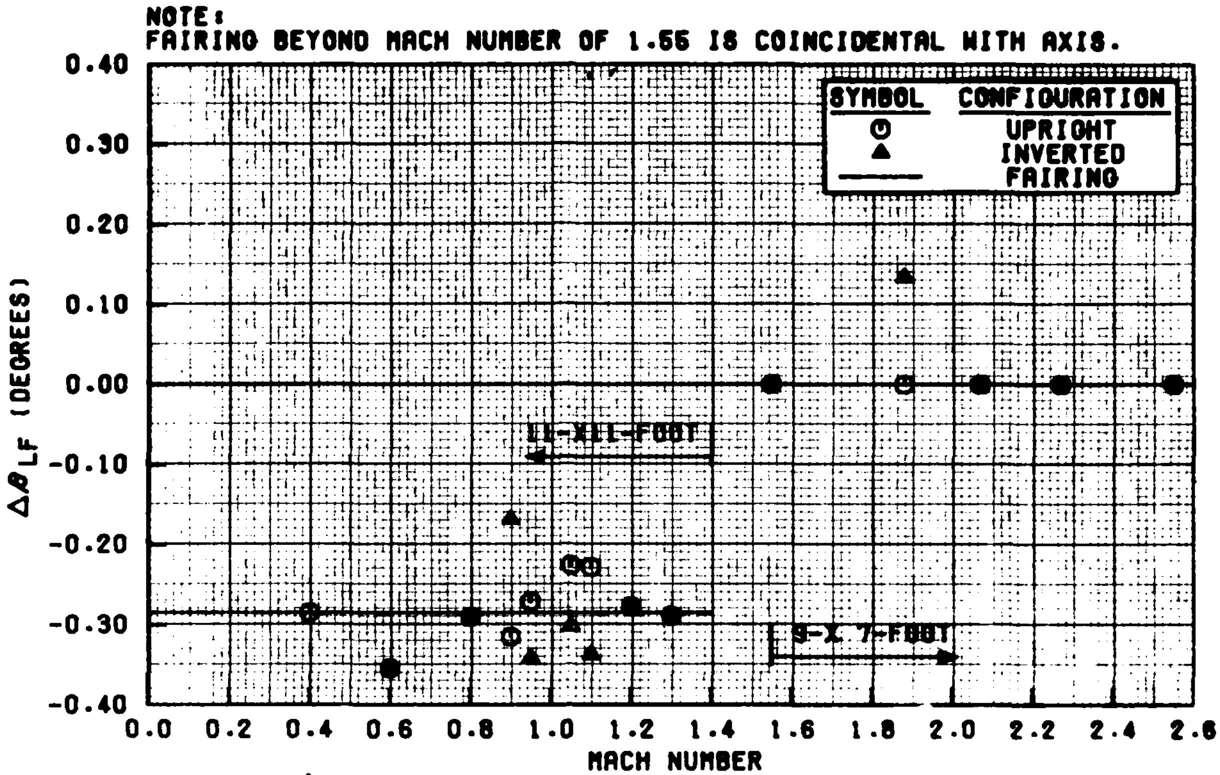


A) UPRIGHT CONFIGURATION, TRUE ANGLE OF SIDESLIP = 0.0 (DEGREES)



B) INVERTED CONFIGURATION, TRUE ANGLE OF SIDESLIP = 0.0 (DEGREES)

FIGURE 10: FLOW-ANGULARITY CHECK OF ORIGINAL ANGLE-OF-SIDESLIP DATA



C) COMBINED CONFIGURATIONS, TRUE ANGLE OF SIDESLIP = 0.0 (DEGREES)

FIGURE 10: FLOW-ANGULARITY CHECK OF ORIGINAL ANGLE-OF-SIDESLIP DATA (CONCLUDED)

DATA BIAS:

The data checks performed to detect flow angularity also disclosed bias in both the angle-of-attack and angle-of-sideslip data. Accounting for the bias was considered very important in establishing confidence in the calibration. Analysis of post calibrations and initial analysis of the NASA/ARC data at AFFTC had arbitrarily removed the bias. Based on the fact that the NBIU is symmetric about a horizontal plane through the centerline except for the angle-of-sideslip vane, the indicated angle of attack should be zero at true angle of attack of zero at supersonic Mach numbers. Similarly, the NBIU is totally symmetric about a vertical plane through the centerline and should have an indicated angle of sideslip of zero when true angle of sideslip is zero. The fact that the calibration data did not confirm these basic assumptions cast doubt on the accuracy numbers stated.

Angle-of-Attack Bias. Bias in angle of attack was noted in both the 11- by 11-foot and 9- by 7-foot data as shown in figure 9(c). The bias in the 11- by 11-foot was explained during evaluation of the procedures used to calibrate the angle-of-attack vanes. It was determined that in the 11- by 11-foot tunnel the vane synchro transmitter was calibrated using a bubble level placed on an angle-of-attack vane. The vanes were misaligned as described in figure 5 and responded aerodynamically like a single vane located at the mean of the two vanes. The combination of calibration procedure and vane-to-vane misalignment resulted in a constant error in indicated angle of attack equal to 0.025 degrees. Based on this discovery, a correction of 0.025 degrees was made to all indicated angle-of-attack data from the 11- by 11-foot tunnel prior to fairing.

Bias in the 9- by 7-foot data as shown in figure 9(c) was faired as 0.095. This bias was never satisfactorily explained and a correction of 0.095 was arbitrarily made to all angle-of-attack data from the 9- by 7-foot tunnel. It should be noted, however, that calibration of the angle-of-attack vanes in the 9- by 7-foot tunnel did not use the bubble-level method previously described. Because the angle-of-attack vanes are mounted vertically (as opposed to horizontally for the 11- by 11-foot tunnel), the calibration was conducted using straight edges, plumb lines, and measurements from the side walls. This procedure is inherently more difficult and less accurate and could have caused or contributed to this very small, yet significant, bias.

A bias correction was made to the angle-of-attack data from both tunnels and the data and fairing were replotted. The resulting data and fairing are shown in figure 11.

NOTES:
1. TRUE ANGLE OF ATTACK AND TRUE ANGLE OF SIDESLIP = 0.0 (DEGREES).
2. FAIRING BEYOND MACH NUMBER OF 1.0 IS COINCIDENTAL WITH AXIS.

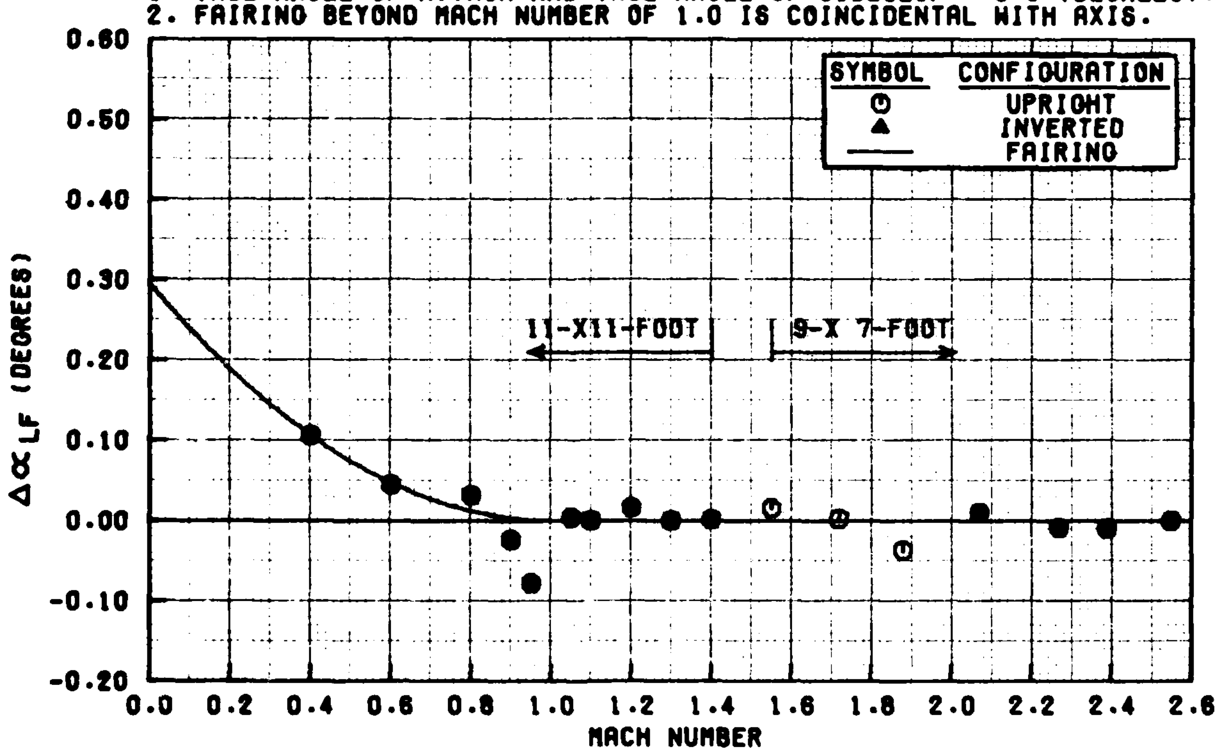


FIGURE 11: FLOW-ANGULARITY CHECK AND FAIRING OF FINAL ANGLE-OF-ATTACK DATA

Angle-of-Sideslip Bias. The bias in angle of sideslip was confined to the 11- by 11-foot wind tunnel data. The bias was determined to be about -0.285 degrees and could not be explained. Since the bias was large relative to claimed accuracy and apparently confined to one tunnel, it appeared to be an instrumentation or data analysis problem. After considerable research and analysis, no documented reason for the bias could be found and the 11- by 11-foot wind tunnel data were arbitrarily shifted 0.285 degrees. It should be noted that, like the angle-of-attack data for the 9- by 7-foot tunnel, the angle-of-sideslip vane for the 11- by 11-foot tunnel was vertical and could not be calibrated using a bubble level. The calibration method relied on measurement from the side walls and could have caused or contributed to the rather large bias.

The bias correction was made to the angle-of-sideslip data from the 11- by 11-foot tunnel and the data and fairing were replotted. The resulting data and fairing are shown in figure 12.

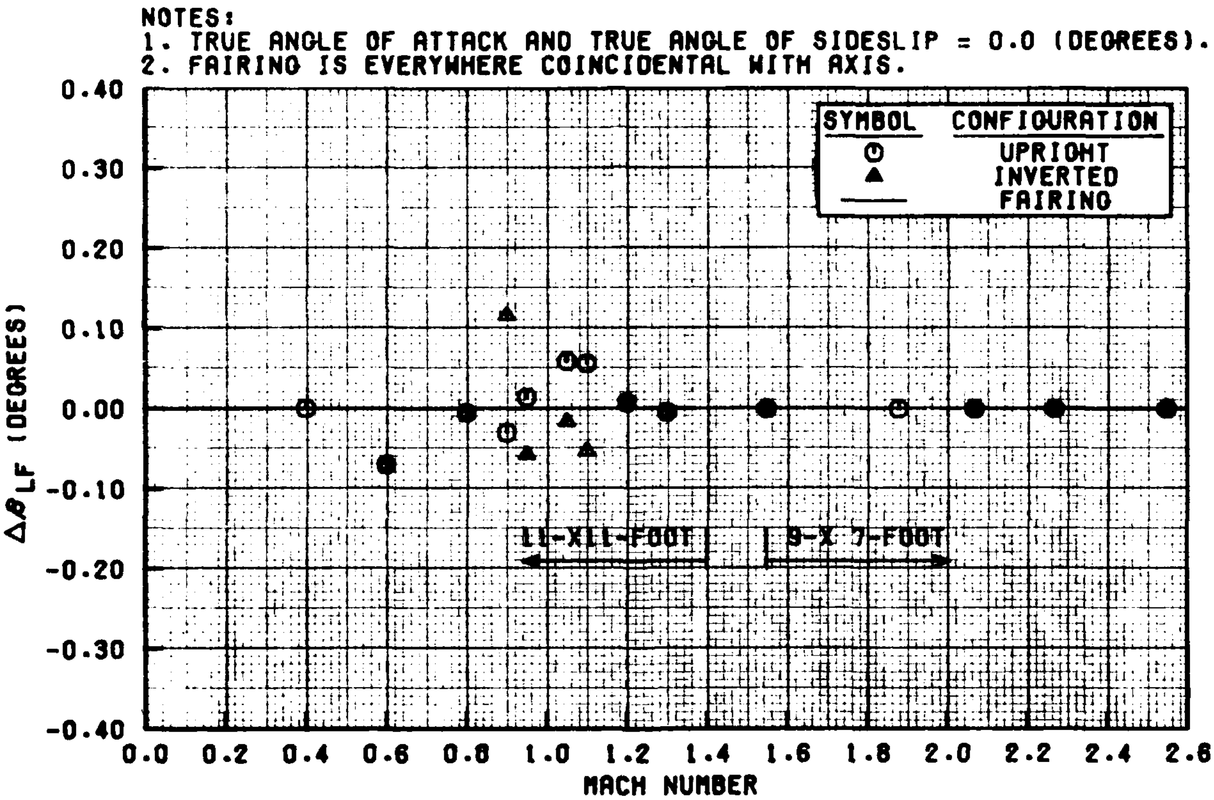


FIGURE 12: FLOW-ANGULARITY CHECK AND FAIRING OF FINAL ANGLE-OF-SIDESLIP DATA

ANGLE-OF-ATTACK DATA SPIKE:

Figure 13 shows a large data "spike" which existed from Mach n.. ..r value of 0.90 to 0.97. The data spike at zero angle of attack was appro.. imately 0.10 degrees in magnitude. The spike was more pronounced at higher angles of attack and was of a magnitude and Mach number location to be easily observed in flight if it existed. Although a considerable amount of flight data was examined, the phenomena was never observed. It was concluded that this was a wind tunnel effect probably associated with a shock reflected from the tunnel wall. An excellent visualization of the shock formation and movement around the NBIU is given in figure 13 of reference 4. Except at 0 degrees angle of attack, data was not available at enough Mach numbers to actually define the characteristics. As a result the data were not changed but the spike was simply faired through. No similar phenomena was noted in the angle-of-sideslip data.

NOTES:
1. TRUE ANGLE OF ATTACK AND TRUE ANGLE OF SIDESLIP = 0.0 (DEGREES).
2. FIGURE INCLUDES ALL VALID DATA: ALPHA, BETA, AND MACH SWEEPS.

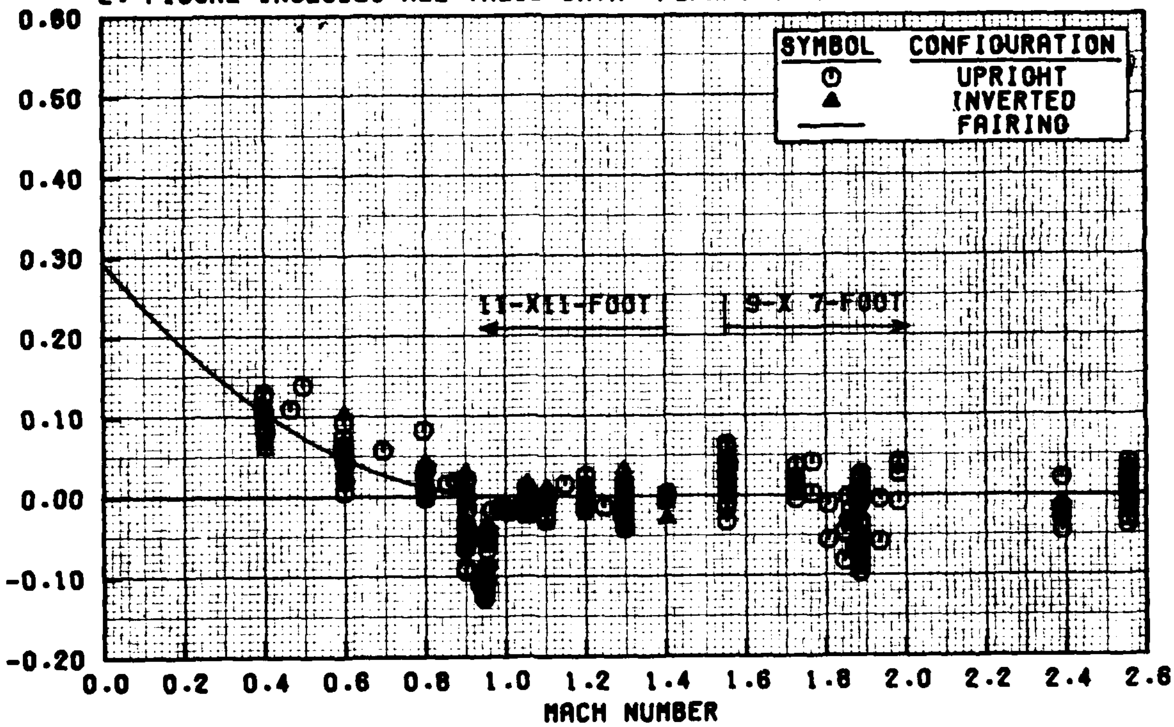


FIGURE 13: ANGLE-OF-ATTACK DATA SPIKE AT TRUE ANGLE OF ATTACK = 0.0

DATA FAIRING

The NASA/ARC data was faired subsequent to being corrected to obtain curves which would define the error in sensed angle of attack and sensed angle of sideslip due to NBIU local flow. The curves would serve as a calibration of the AFFTC NBIU flow angle sensing and could be implemented in a computer program for use in data reduction programs. The fairing, which was accomplished by a combination of hand and mathematical techniques, was done within conflicting constraints. The curves needed to be as accurate as possible yet simple enough to be easily implemented. It was essential to obtain the best possible calibration of angle of attack at zero angle of sideslip since this is the primary condition for obtaining most performance data and the most critical application for the NBIU. Accuracy requirements were less stringent for fairing angle of attack at angles of sideslip and for fairing angle of sideslip. The final fairings obtained were considered adequate for all uses of the NBIU and were easily implemented in a standard software package. There were, however, data at high angles of attack and at high angles of sideslip which were ignored because it was felt the data were influenced by the wind tunnel and were not characteristic of the NBIU. Users who have high accuracy requirements in these areas should examine the comparison of the fairings and angle-of-attack data in Appendix A and comparison of the fairings and angle-of-sideslip data in Appendix B to determine if the fairings match the test data acceptably well. These users should be prepared to expend a lot of effort to correct and examine data and assure themselves the data are accurate if they choose to refair these areas.

ANGLE-OF-ATTACK FAIRING:

The angle-of-attack data were systematically faired based on theoretically predicted characteristics with the levels empirically adjusted to match the data. Based on studies of theoretical parameters, Mach effects were predicted to vary linearily with Mach number squared. The data substantiated this almost without exception and all working plots were done in terms of Mach squared. Theoretical analysis of flow around a cylindrical body predicted that errors associated with angle of attack should be zero at zero angle of attack, build slowly but with increasing speed to a maximum at 45 degrees angle of attack and return to zero at 90 degrees angle of attack. Attempts to fair the data with several functions which met this criteria led to use of the functional relationship

$$\Delta\alpha_{LF} = f(\sin 2\alpha_B,\ \sin^2 2\alpha_B)$$

which worked well except where shocks from other parts of the NBIU interfered. This approach resulted in an iteration when determining α_B from α_V but was technically the best approach. The data were faired by fairing angle of attack at zero angle of sideslip; then an adjustment was made to the fairings by adding a small increment to correct to other angles of sideslip.

Fairing of the angle-of-attack data at zero angle of sideslip began by fairing the data for angle of attack and angle of sideslip of zero. The fairing which is shown in figure 11 along with the data has a large deviation from zero at low Mach numbers which decreases to zero at a Mach of 1.0. This deviation was probably caused by the pressure field of the angle-of-sideslip vane affecting flow around the angle-of-attack vanes. The effect of the angle-of-sideslip vane was temporarily subtracted from the subsonic angle-of-attack data during further fairing. The data were then plotted as $\Delta\alpha_{LF}$ versus Mach number squared with lines of α_B. The data were easily faired as straight lines in the subsonic region and supersonically beyond Mach number of 1.51. However, in the transonic region there were complications in fairing. Large changes in the magnitude of the value of $\Delta\alpha_{LF}$ and sudden changes in its slope with Mach number made fairing difficult. Schlerein photographs taken for flow visualization were examined in an attempt to explain the rapid changes. The flow visualization studies, which are partially documented in reference 4, indicated the sudden changes in characteristics were correlated with the movement of shocks over the angle-of-attack vanes. The data were then faired with sharp corners. The resulting curves for angle of attack at zero angle of sideslip plotted versus Mach number with lines of α_V are shown in Figure 14. The same information with the subsonic deviation restored is shown in figure 15(a).

The fairings of angle of attack at zero angle of sideslip were compared with data at other angles of sideslip. The comparison showed good agreement with data at all angles of sideslip for the supersonic Mach range. Subsonically there were deviations between the fairings and data which required correction. A small incremental correction was developed which was a function of Mach number and true angle of sideslip. The effect of this correction will be shown in the Results section of this memorandum.

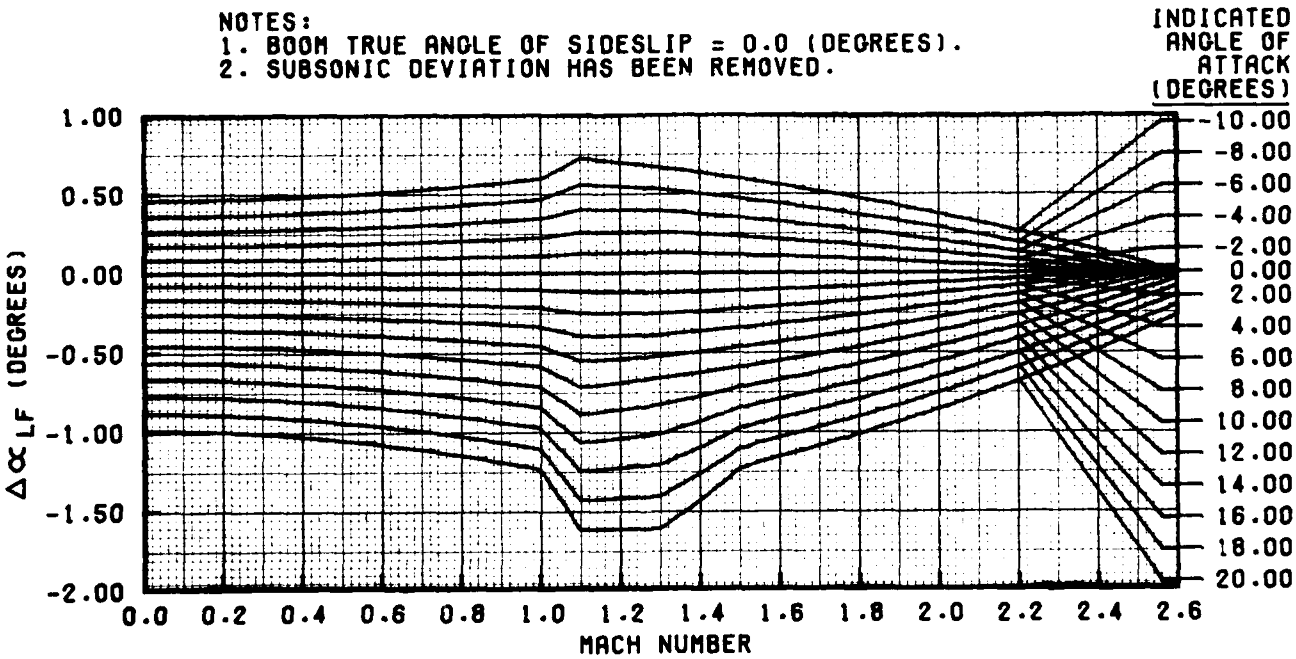
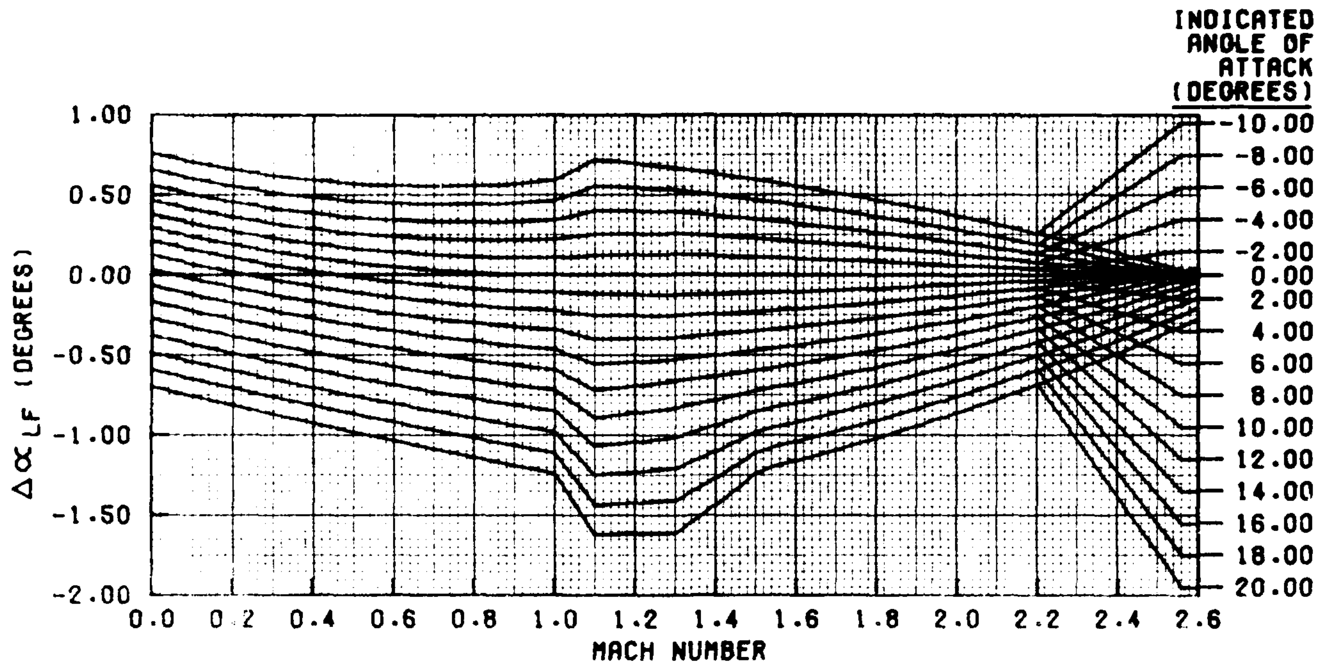
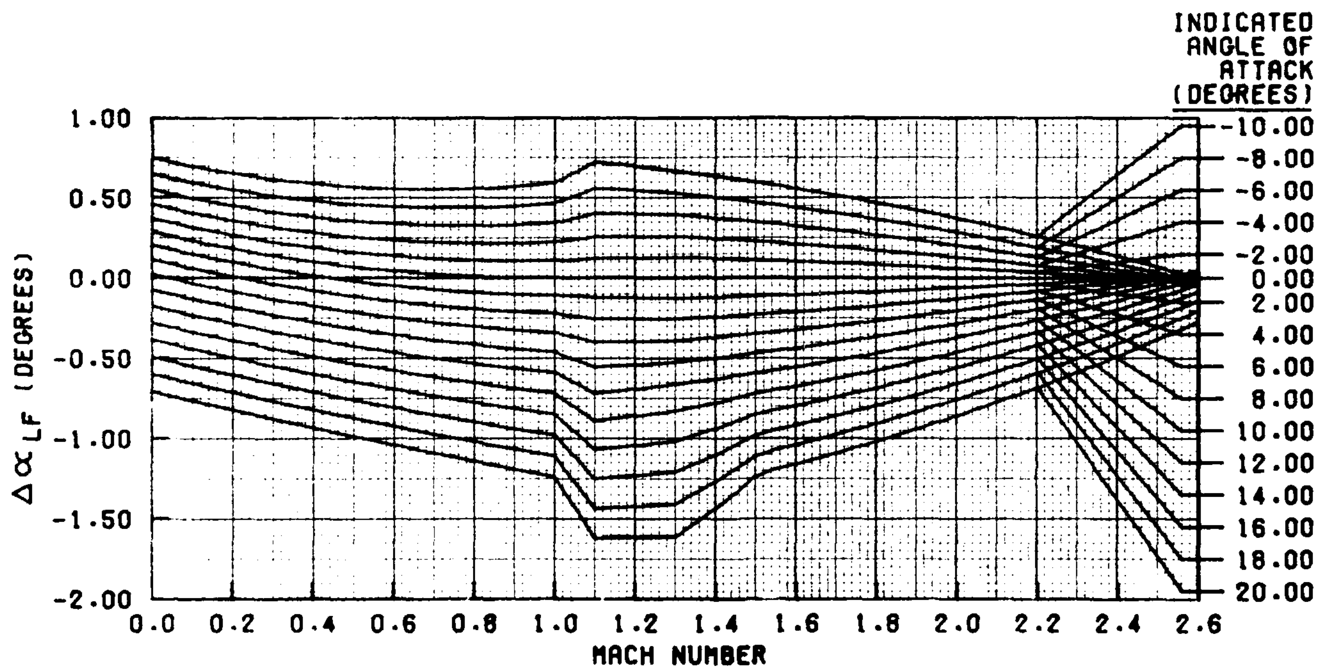


FIGURE 14: INITIAL FAIRING OF ANGLE-OF-ATTACK ERROR DUE TO LOCAL FLOW

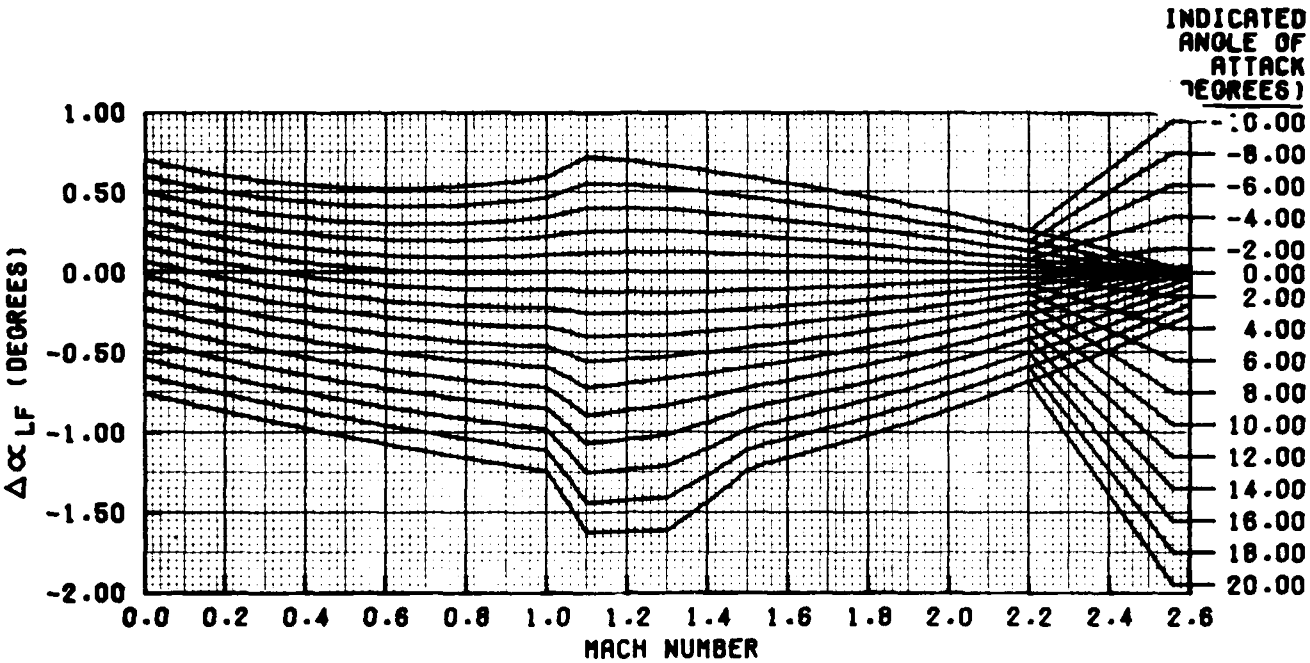


A) BOOM TRUE ANGLE OF SIDESLIP = 0.0 (DEGREES)

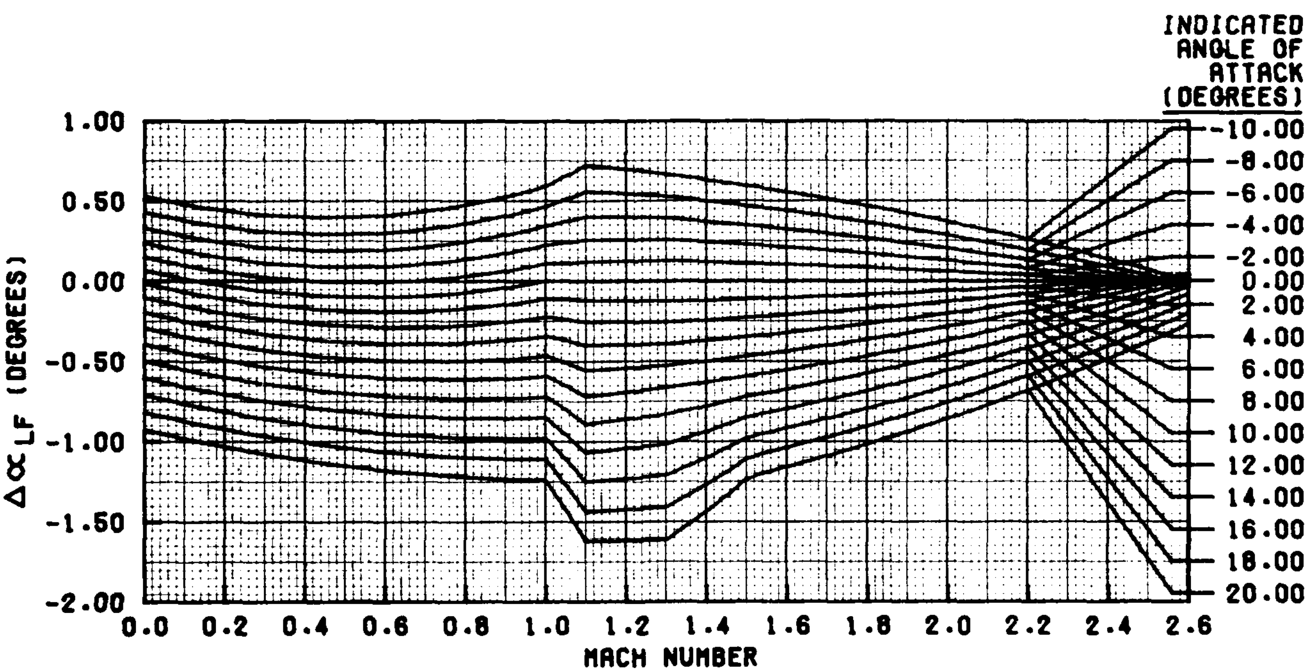


B) BOOM TRUE ANGLE OF SIDESLIP = ±2.0 (DEGREES)

FIGURE 15: SUMMARY OF ANGLE-OF-ATTACK ERROR DUE TO LOCAL FLOW



C) BOOM TRUE ANGLE OF SIDESLIP = ±5.0 (DEGREES)



D) BOOM TRUE ANGLE OF SIDESLIP = ±10.0 (DEGREES)

FIGURE 15: SUMMARY OF ANGLE-OF-ATTACK ERROR DUE TO LOCAL FLOW (CONCLUDED)

ANGLE-OF-SIDESLIP FAIRING:

The angle of-sideslip data were faired in a manner very similar to the angle-of-attack data. The data were very consistent and the characteristics similar to angle of attack when plotted versus Mach number squared. The same functional relationship was used for angle of sideslip as for angle of attack so that

$$\Delta\beta_{LF} = f(\sin 2\beta_B, \sin^2 2\beta_B)$$

The analysis was very consistent and showed good characteristics up to a Mach number of 1.30. At Mach number of 1.30 the characteristics changed slope with Mach number in a manner similar to angle of attack, and were again consistent to a Mach number of 1.51. Beyond a Mach number of 1.51, the data showed little correlation between Mach numbers and had large, inconsistent changes in characteristics. For Mach number values of 1.91, 2.11, 2.31, 2.41, and 2.54 the characteristics were so radically different that each Mach number was faired independently and straight line interpolation with Mach number squared was used. A plot of the characteristics for angle of attack of 0.0 is shown in figure 16(b). The characteristics beyond a Mach number of 1.51 are caused by numerous shocks impacting the angle-of-sideslip vane. There is little reason to believe that the straight line segment accurately represent the characteristics except in the immediate vicinity of test data points.

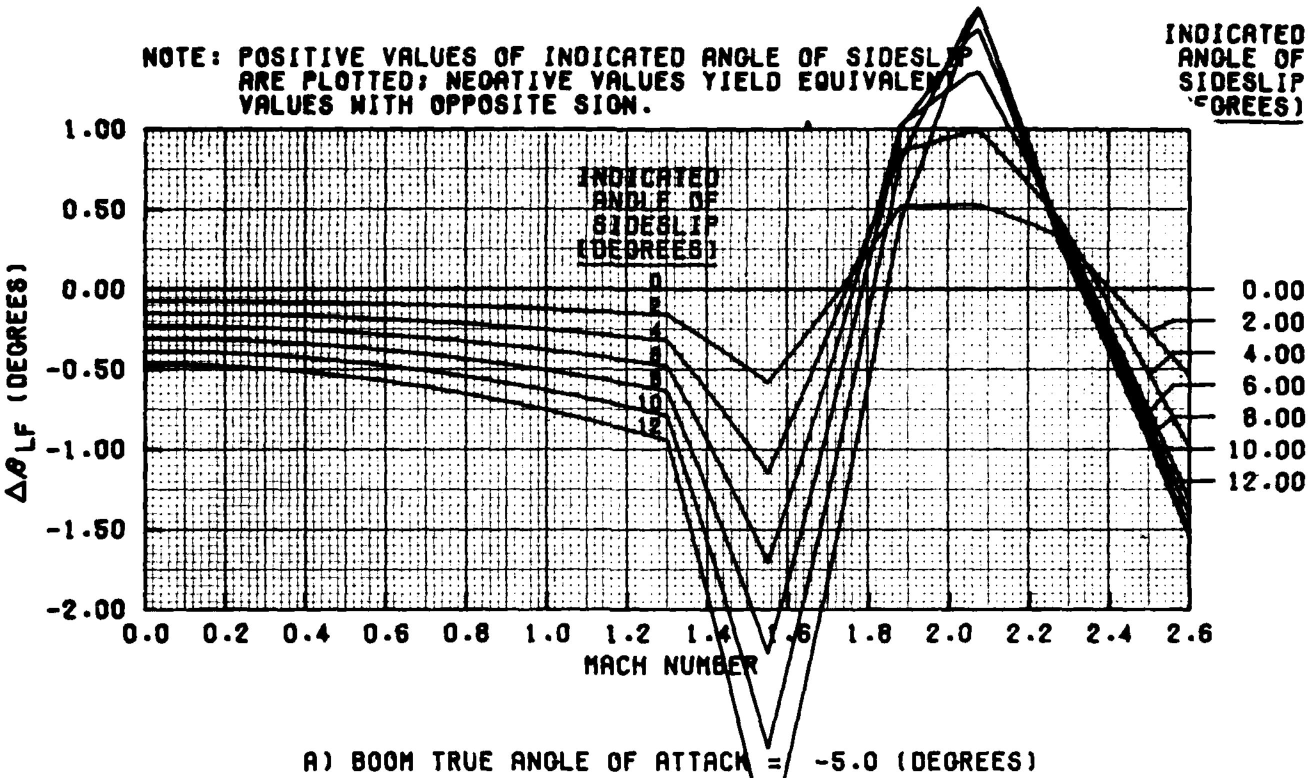
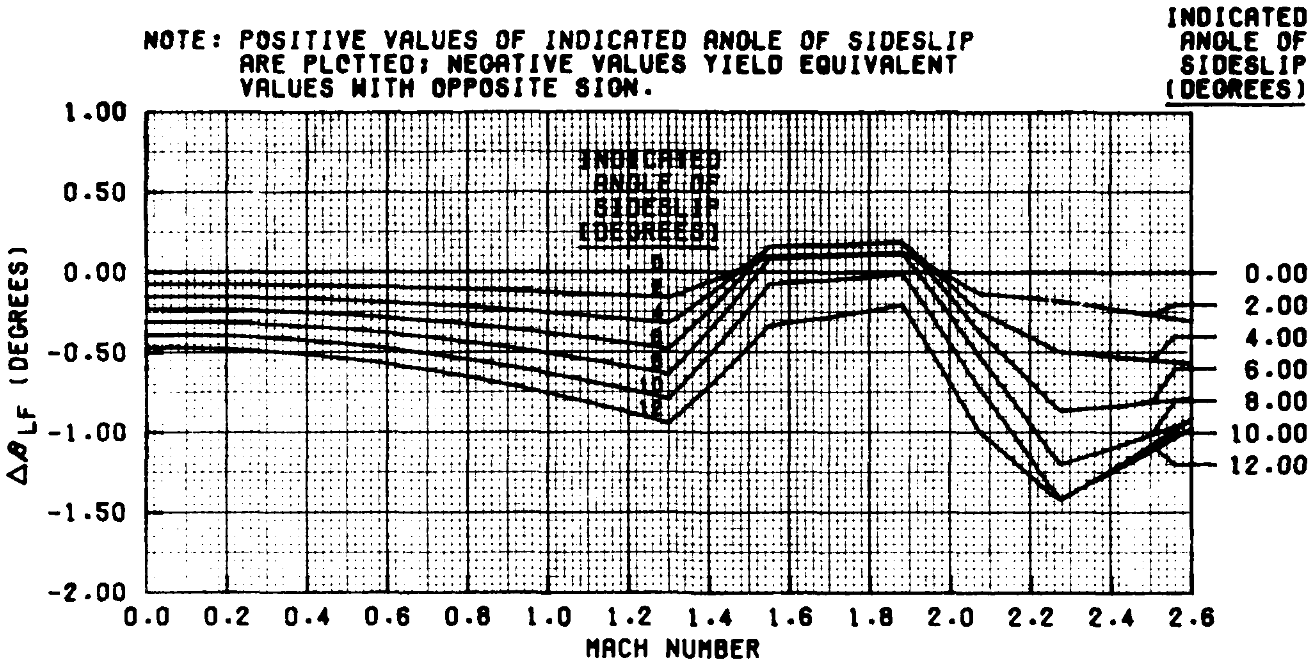
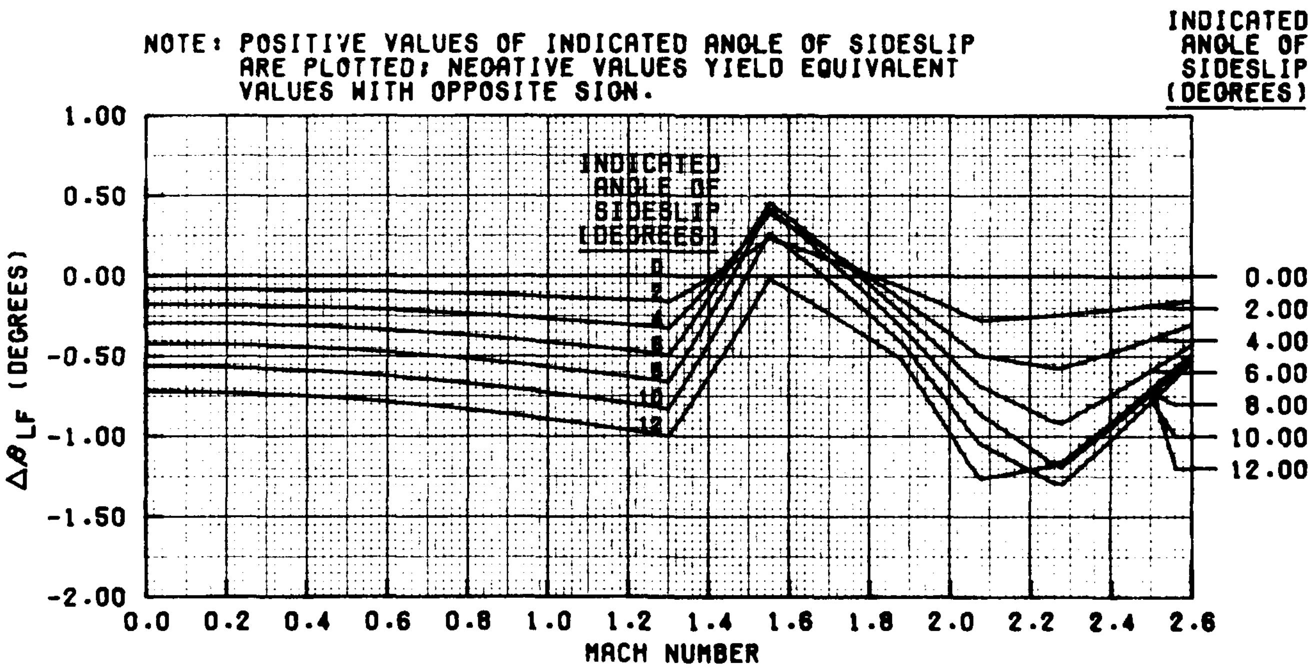


FIGURE 16: SUMMARY OF ANGLE-OF-SIDESLIP ERROR DUE TO LOCAL FLOW

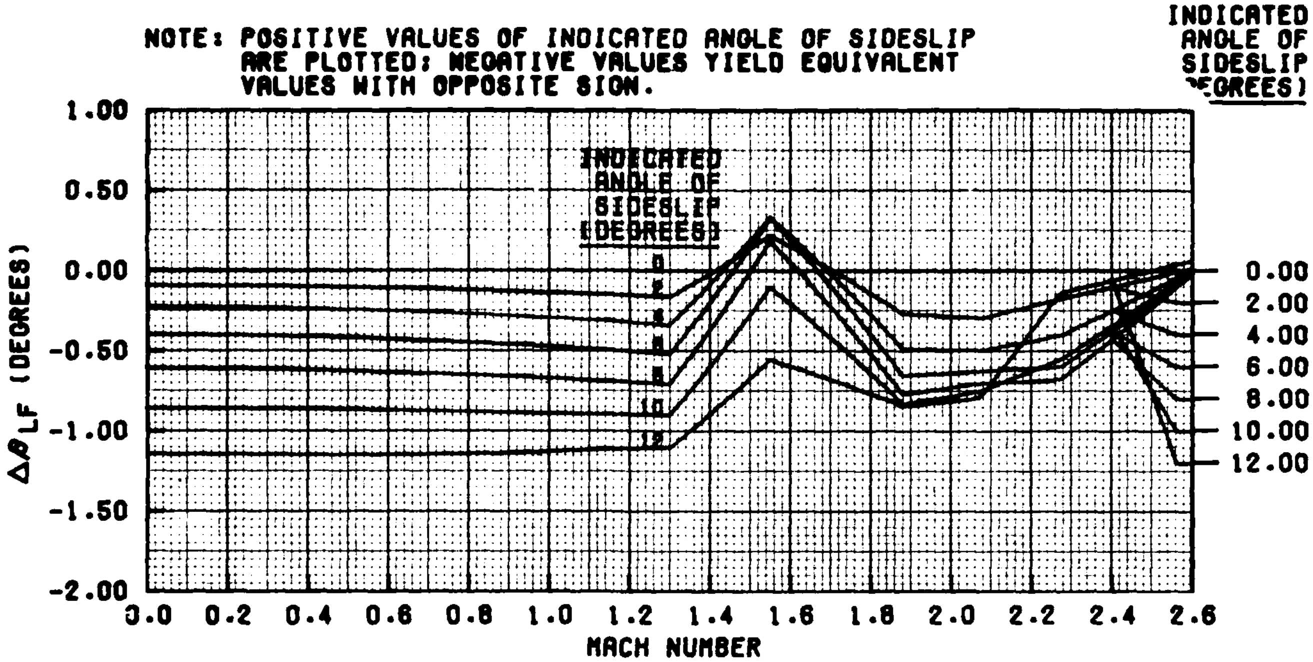


C) BOOM TRUE ANGLE OF ATTACK = 5.0 (DEGREES)

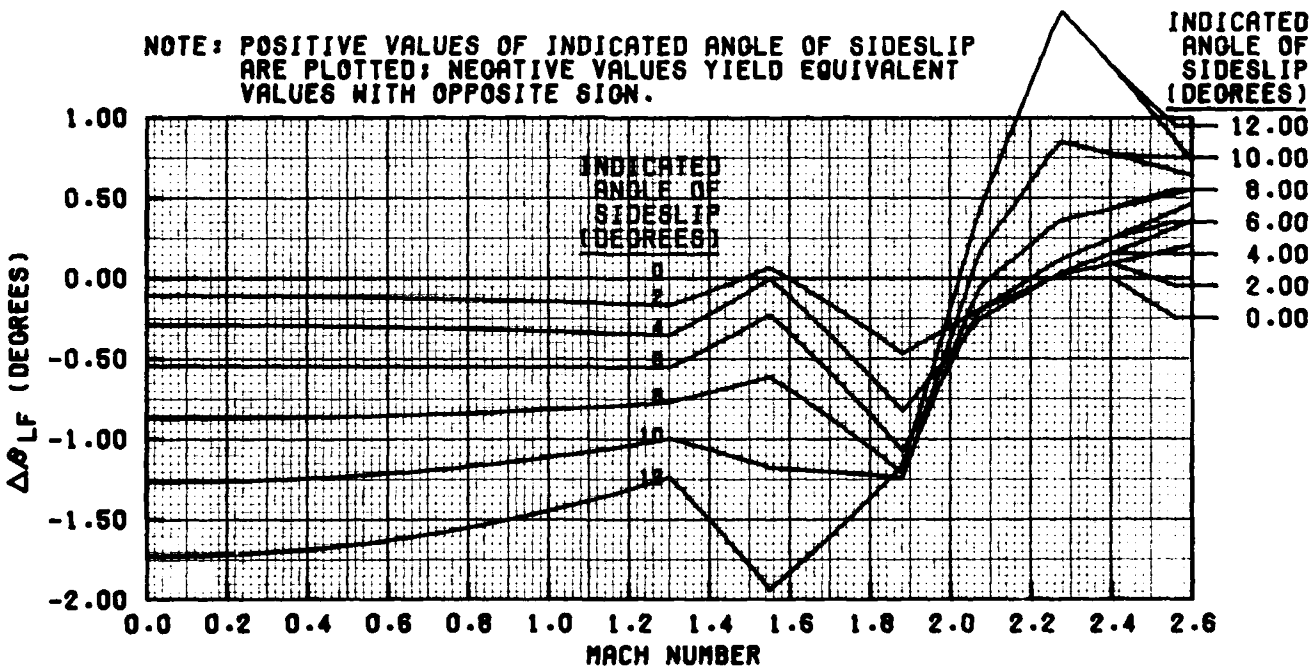


D) BOOM TRUE ANGLE OF ATTACK = 10.0 (DEGREES)

FIGURE 16: SUMMARY OF ANGLE-OF-SIDESLIP ERROR DUE TO LOCAL FLOW (CONTINUED)



E) BOOM TRUE ANGLE OF ATTACK = 15.0 (DEGREES)



F) BOOM TRUE ANGLE OF ATTACK = 20.0 (DEGREES)

FIGURE 16: SUMMARY OF ANGLE-OF-SIDESLIP ERROR DUE TO LOCAL FLOW (CONCLUDED)

RESULTS

The result of the analysis of the NASA/ARC test and data was a fairing of the error in angle of attack and angle of sideslip. These fairings were effective calibrations of the flow sensing element of the AFFTC NBIU. The fairings were compared extensively with the corrected test data and showed acceptable agreement throughout the envelope of the data. The fairings were implemented in a series of FORTRAN IV subroutines useable in data reduction by all flight test programs having an NBIU with compatible configuration.

ANGLE-OF-ATTACK RESULTS:

The fairings of the angle-of-attack data are summarized in figure 15. The format of the plots was changed from the format used in fairing to plot error in angle of attack versus Mach number with lines of indicated angle of attack. Figure 15(a) shows an error in indicated angle of attack at zero angle of sideslip across the Mach range plotted. The magnitude of the error increases steadily through the subsonic and transonic regions and levels off at its largest magnitude between Mach number values of 1.1 and 1.3. The error then decreases uniformly to zero around Mach number value of 2.5 where the data indicates the error changes sign and begins to increase in magnitude again. The error at indicated angle of attack of 0.0 is large at low Mach numbers due to the pressure field of the angle-of-sideslip vane and decreases to zero at Mach number value of 1.0. The error also increases and decreases with the value of indicated angle of attack. Effects of angle of sideslip, as shown by figure 15(b), 15(c), and 15(d) are confined to the subsonic region where they are large at low Mach numbers and decrease to zero at Mach number value of 1.0. As expected, the errors are dependent only on the magnitude of the sideslip and not on the direction.

The fairings of the angle-of-attack data are compared with the NASA/ARC data in Appendix A with generally good agreement. Agreement is excellent at angle of sideslip of 0.0 both in level and trends, the exception being at Mach number values of 0.90 and 0.95 (especially 0.95) where the data are displaced because of a reflected shock. The agreement between the fairing and data degrades with angle of sideslip in level, scatter, and short term trends, but is generally good in long term trends. The data was faired in this manner because of lower confidence in the data at large angles of sideslip and the reduced accuracy usually required at higher angles of sideslip. Additionally, many of the short-term trends were possibly due to the wind tunnel rather than being NPIU characteristics. Reynolds number effects were investigated at Mach number values of 0.90, 1.30, and 1.51. The data comparison shows negligible effect due to Reynolds number.

ANGLE-OF-SIDESLIP RESULTS:

The fairings of the angle-of-sideslip data are summarized in figure 16. The format of the plots was changed from the format used in fairing to plot error in angle of sideslip versus Mach number with lines of indicated angle of sideslip. Figure 16(b) shows an error in indicated angle of sideslip at zero angle of attack across the Mach range plotted. The magnitude of the error increases steadily through the subsonic and transonic regions to a Mach number value of 1.3. At Mach number value of 1.3 the curves start to deviate rapidly to a larger negative value and at 1.5 begin to deviate

toward positive values as shocks from forward portions of the NBIU interact with the angle-of-sideslip vane. Effects of angle of attack on the angle-of-sideslip error are shown in figures 16(a), 16(c), 16(d), 16(e), and 16(f). As expected, the effects of angle of attack on angle-of-sideslip error were not symmetric.

The fairings of the angle-of-sideslip data are compared with the NASA/ARC data in Appendix B with generally good agreement. Agreement is excellent at low and moderate angles of attack and sideslip up to a Mach number value of 1.3. Beyond a Mach number value of 1.3 the fits are, at best, good with more scatter and more short-term, ordered deviations from the data.

NBIU CALIBRATION SOFTWARE:

The fairings of the NASA/ARC data were developed into a standard software package for use in data reduction. All curves and fairings presented in this memorandum were machine prepared using this software. The software consists of six subroutines but the only user interface is with a subroutine called ANGLES. The calling statement

```
CALL ANGLES (ALFAV,BETAV,AMCT,CONVRA,CONVRB,ALPHA,BETA,IFLAG)
```

can be inserted in the users code to determine the true angle of attack and angle of sideslip from the indicated values. The indicated angle of attack, ALFAV, indicated angle of sideslip, BETAV, and freestream Mach number, AMCT, are input. The convergence factor for angle of attack, CONVRA, and convergence factor for angle of sideslip, CONVRB, determine the maximum difference in two consecutive estimates of the true angles which will end internal iterations. These values will normally be set to zero prior to the first call so that the default value of 0.000001 will be used but they can be input if the user desires. The true value of angle of attack, ALPHA, and true angle of sideslip, BETA, are output along with an error flag, IFLAG. The error flag is of little concern to the user who uses the software unmodified and selects the default convergence factors. Users who do wish to change either the software or convergence factors should consult the Programmer's Guide located in Appendix C of this memorandum.

Potential users of this software should be aware of two important restrictions on its use. The calibration is strictly valid only for the hardware configuration tested which had two unique features. The first feature was a modified pitot-static adapter and different pitot-static head than most AFFTC NBIUs. The user should consider changing the configuration of his NBIU to match the documented configuration prior to the flight test program. If this is not practical, the software can and has been used to correct data from other AFFTC NBIU configurations. Although this is not the recommended approach, it gives more accurate results than previous calibrations plotting true versus indicated angle of attack from flight data and fairing the resulting curve. The second feature is a noseboom which is unique to the TACT program. The effect of noseboom upwash was not removed from the calibration data. Correction for differences in upwash due to significant differences in noseboom configuration should be made using the procedure in reference 7 or some other acceptable method (Recommendation 3).

CONCLUSIONS AND RECOMMENDATIONS

The use of the NBIU calibration developed from data from the NASA/ARC tests significantly improves the accuracy of angle-of-attack and angle-of-sideslip data obtained from AFFTC NBIU's and consequently improves the accuracy of the excess thrust calculated from the NBIU longitudinal acceleration. The use of the software coupled with flight test adjustment improves results over a solely flight test calibration whether the production NBIU or TACT variant is used.

> 1. *The production software should be used on all flight test programs utilizing AFFTC NBIU's. (page 12)*

The best accuracy and highest confidence in the results, however, is obtained if the TACT variant is used.

> 2. *All new AFFTC NBIU's should be built in the TACT configuration and all existing NBIU's should be modified when practical. (page 15)*

Since the noseboom configuration on which the NBIU is mounted can significantly affect angle-of-attack errors, a correction for differences in upwash due to differences in noseboom configuration should be made.

> 3. *Correction for differences in upwash due to differences in noseboom configuration should be made using the procedure in reference 7 or some other acceptable method. (page 45)*

LIST OF REFERENCES

1. Gomillion, G.R.: Wind Tunnel Calibration Test for Angle-of-Attack and Sideslip Vanes of a Full-Scale Flight Path Accelerometer at Mach Numbers from 0.2 to 1.3, AEDC-TR-71-27 (AD880621), February 1971.

2. Uselton, James C.; Shadow, T.O.: Results of Wind Tunnel Tests on a Flight Path Accelerometer at Mach Numbers from 0.3 to 3.0, AEDC-TR-71-260, February 1972.

3. Shadow, T.O.: Wind Tunnel Investigation of the Transonic Aerodynamic Characteristics of a Full-Scale Flight Path Accelerometer (Follow-On Test), AEDC-TR-72-1, February 1972.

4. Sakamoto, Glenn M.: Aerodynamic Characteristics of a Vane Flow Angularity Sensor System Capable of Measuring Flightpath Accelerations for the Mach Number Range from 0.40 to 2.54, NASA TN D-8242, May 1976.

5. Pirrello, C.J.; Hardin, R.D.; Heckhart, M.V.; and Brown, K.R.: An Inventory of Aeronautical Ground Research Facilities; Volume I: Wind Tunnels, NASA CR-1874, November 1971.

6. Daugherty, James C: "Techniques and Procedures Used for Wind Tunnel Tests in Support of the TACT Correlation Program", Symposium on Transonic Aircraft Technology (TACT), AFFDL-TR-78-100, August 1978.

7. Rawlings, Kenneth: A Method of Estimating Upwash Angle at Noseboom-Mounted Vanes, AFFTC-TIM-81-1, June 1981.

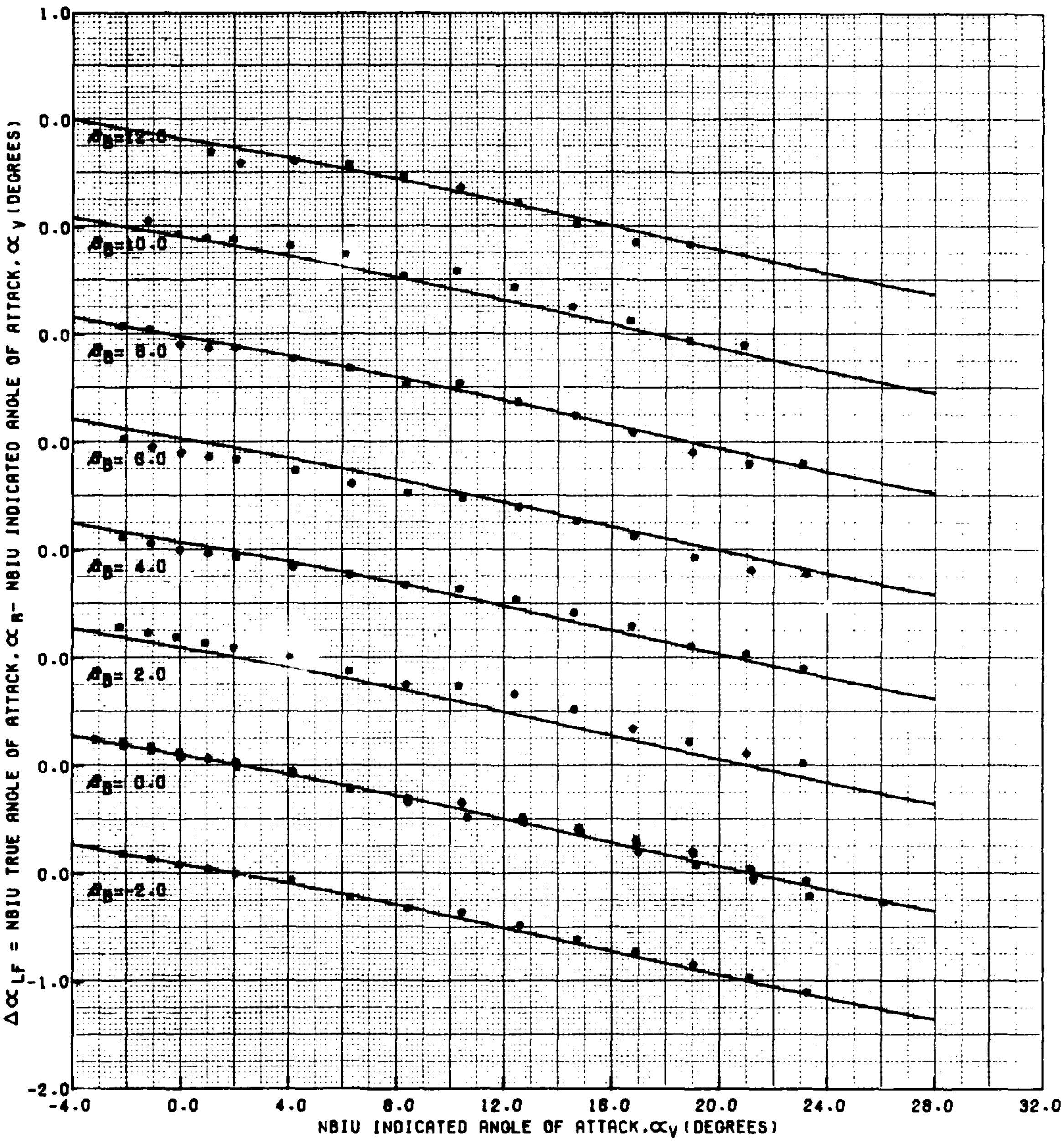
APPENDIX A
COMPARISON OF ANGLE-OF-ATTACK DATA AND FAIRINGS

Data from the NASA/ARC calibration of the AFFTC NBIU were plotted on the same grid as the AFFTC fairing. The data from test 11/97-731 were first corrected as described in the body of this memorandum and plotted. The AFFTC fairing as obtained from the production software was also plotted. Figure A1 presents the error in angle of attack due to local flow for all test Mach numbers and angles of sideslip for a range of indicated angles of attack.

AFFTC NBIU CALIBRATION
NASA/ARC 11- X 11-FOOT TUNNEL
TEST 11/97-731 - 1 MAY 1973

NOTES:
1. ACTUAL MACH NUMBER IS 0.40.
2. DATA HAS BEEN CORRECTED FOR 0.025 BIAS.

SYMBOL	EXPLANATION
ʘ	$R_E/L = 2.0\times10^6$ (/FOOT)
——	AFFTC CURVE

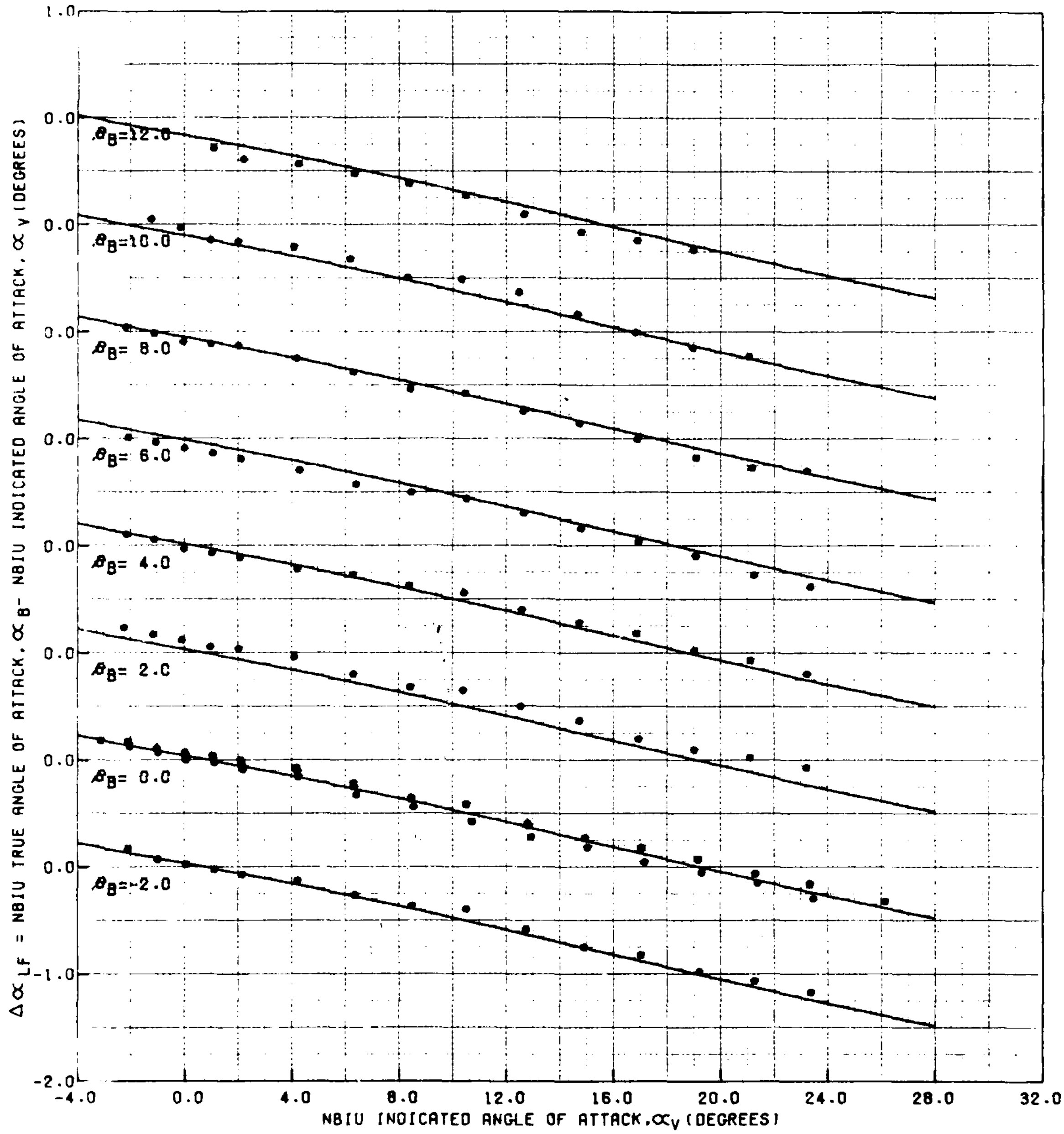


A) REFFRENCE MACH NUMBER = 0.40
FIGURE A1: ANGLE OF ATTACK ERROR DUE TO LOCAL FLOW

AFFTC NBIU CALIBRATION
NASA/ARC 11- X 11-FOOT TUNNEL
TEST 11/97-731 - 1 MAY 1973

SYMBOL	EXPLANATION
⊙	$R_E/L = 2.6 \times 10^6$ (/FOOT)
- —	AFFTC CURVE

NOTES:
1. ACTUAL MACH NUMBER IS 0.60.
2. DATA HAS BEEN CORRECTED FOR 0.025 BIAS.

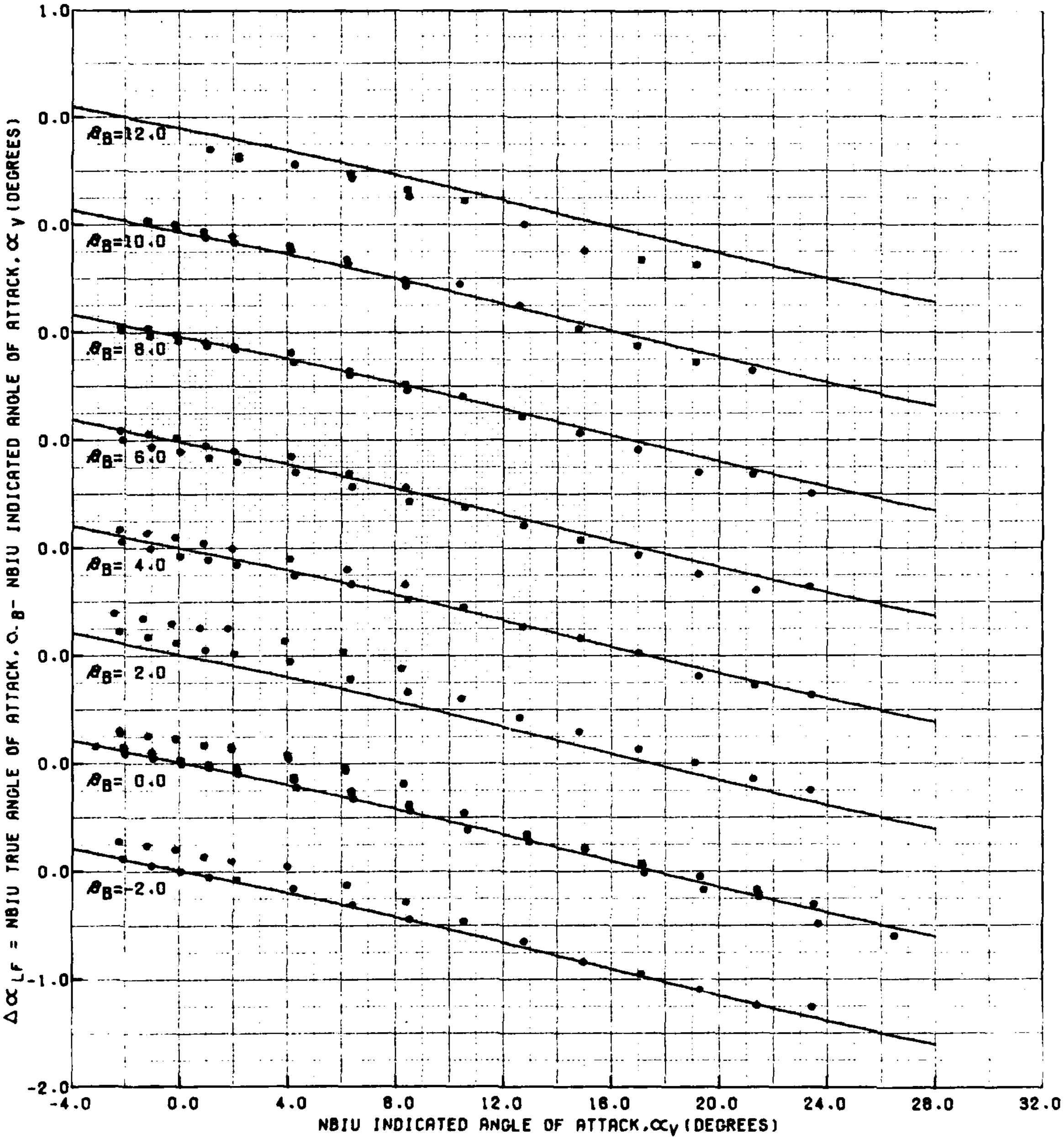


B) REFERENCE MACH NUMBER = 0.60
FIGURE A1: ANGLE OF ATTACK ERROR DUE TO LOCAL FLOW (CONTINUED)

AFFTC NBIU CALIBRATION
NASA/ARC 11- X 11-FOOT TUNNEL
TEST 11/97-731 - 1 MAY 1973

NOTES:
1. ACTUAL MACH NUMBER IS 0.80.
2. DATA HAS BEEN CORRECTED FOR 0.025 BIAS.

SYMBOL	EXPLANATION
⊙	$R_E/L = 2.1 \times 10^6$ (/FOOT)
——	AFFTC CURVE

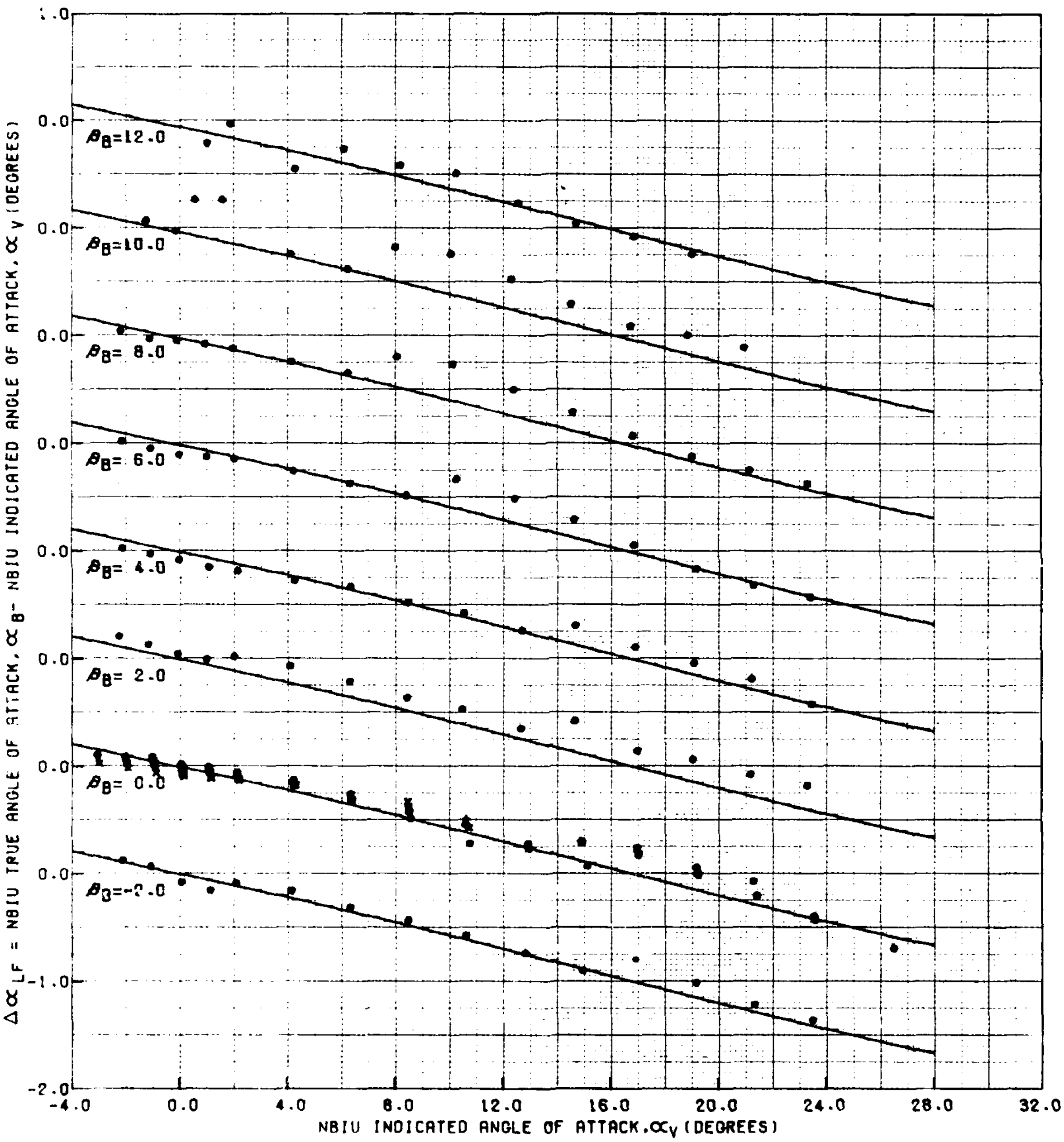


C) REFERENCE MACH NUMBER = 0.80
FIGURE A1: ANGLE OF ATTACK ERROR DUE TO LOCAL FLOW (CONTINUED)

AFFTC NBIU CALIBRATION
NASA/ARC 11- X 11-FOOT TUNNEL
TEST 11/97-731 - 1 MAY 1973

NOTES:
1. ACTUAL MACH NUMBER IS 0.90.
2. DATA HAS BEEN CORRECTED FOR 0.025 BIAS.

SYMBOL	EXPLANATION
⊙	$R_E/L = 2.0\times10^6$ (/FOOT)
+	$R_E/L = 3.3\times10^6$ (/FOOT)
×	$R_E/L = 5.5\times10^6$ (/FOOT)
——	AFFTC CURVE

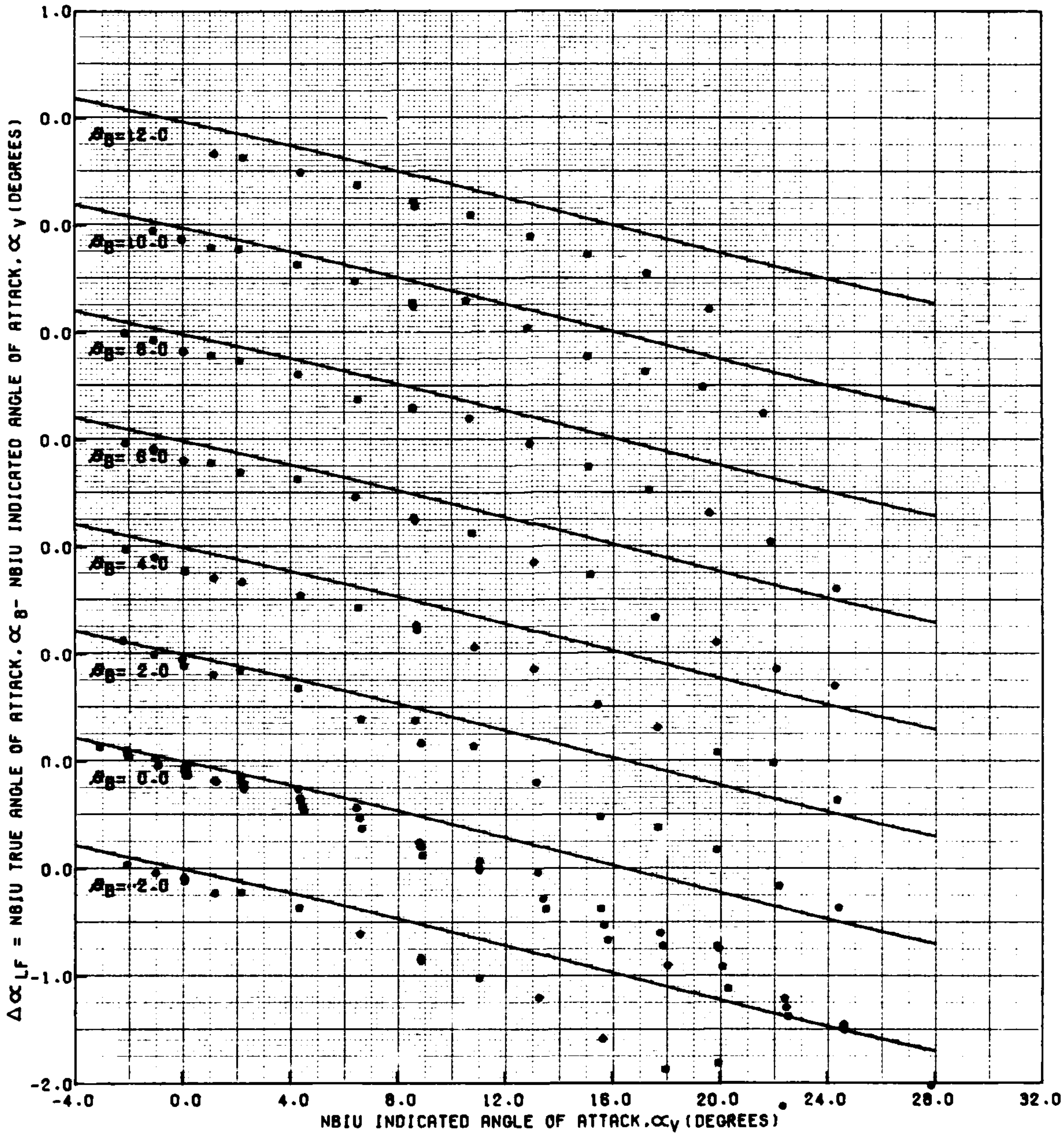


D) REFERENCE MACH NUMBER = 0.90
FIGURE A1: ANGLE OF ATTACK ERROR DUE TO LOCAL FLOW (CONTINUED)

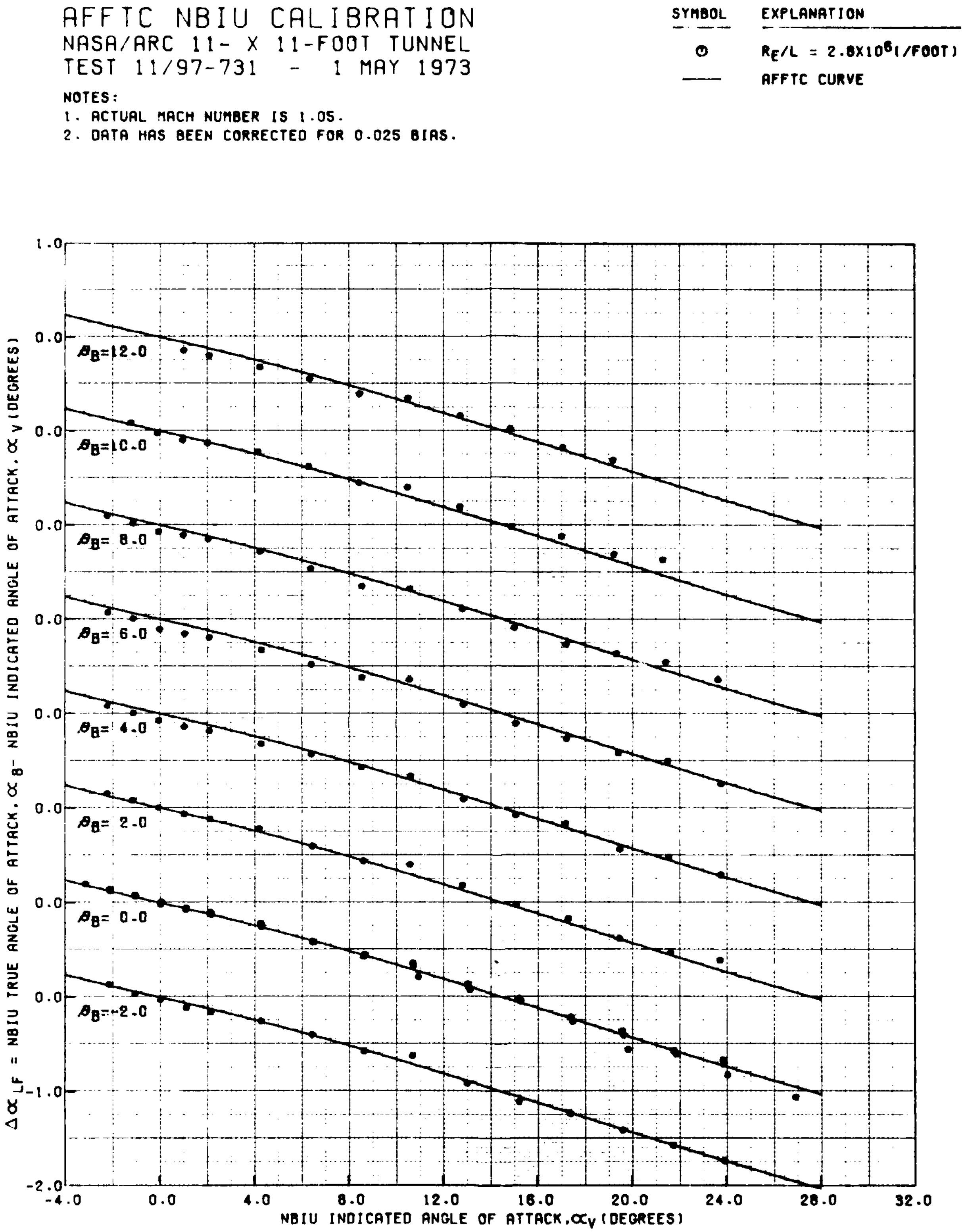
AFFTC NBIU CALIBRATION
NASA/ARC 11- X 11-FOOT TUNNEL
TEST 11/97-731 - 1 MAY 1973

NOTES:
1. ACTUAL MACH NUMBER IS 0.95.
2. DATA HAS BEEN CORRECTED FOR 0.025 BIAS.

SYMBOL	EXPLANATION
⊙	$R_E/L = 1.8 \times 10^6$ (/FOOT)
——	AFFTC CURVE



E) REFERENCE MACH NUMBER = 0.95
FIGURE A1: ANGLE OF ATTACK ERROR DUE TO LOCAL FLOW (CONTINUED)

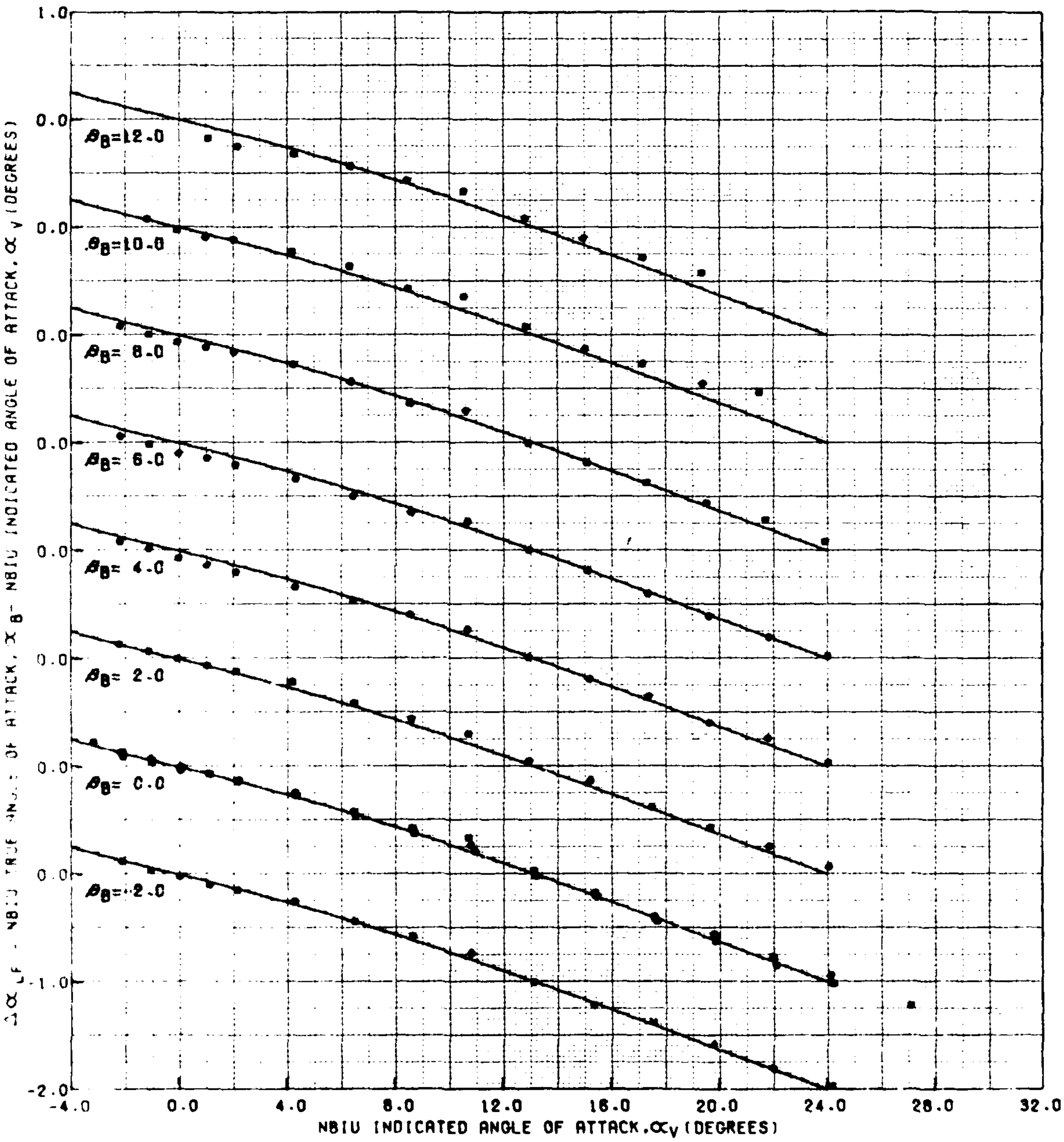


F) REFERENCE MACH NUMBER = 1.05
FIGURE A1: ANGLE OF ATTACK ERROR DUE TO LOCAL FLOW (CONTINUED)

AFFTC NBIU CALIBRATION
NASA/ARC 11- X 11-FOOT TUNNEL
TEST 11/97-731 - 1 MAY 1973

NOTES:
1. ACTUAL MACH NUMBER IS 1.10.
2. DATA HAS BEEN CORRECTED FOR 0.025 BIAS.

SYMBOL	EXPLANATION
⊙	$R_E/L = 2.9 \times 10^6$ (/FOOT)
———	AFFTC CURVE

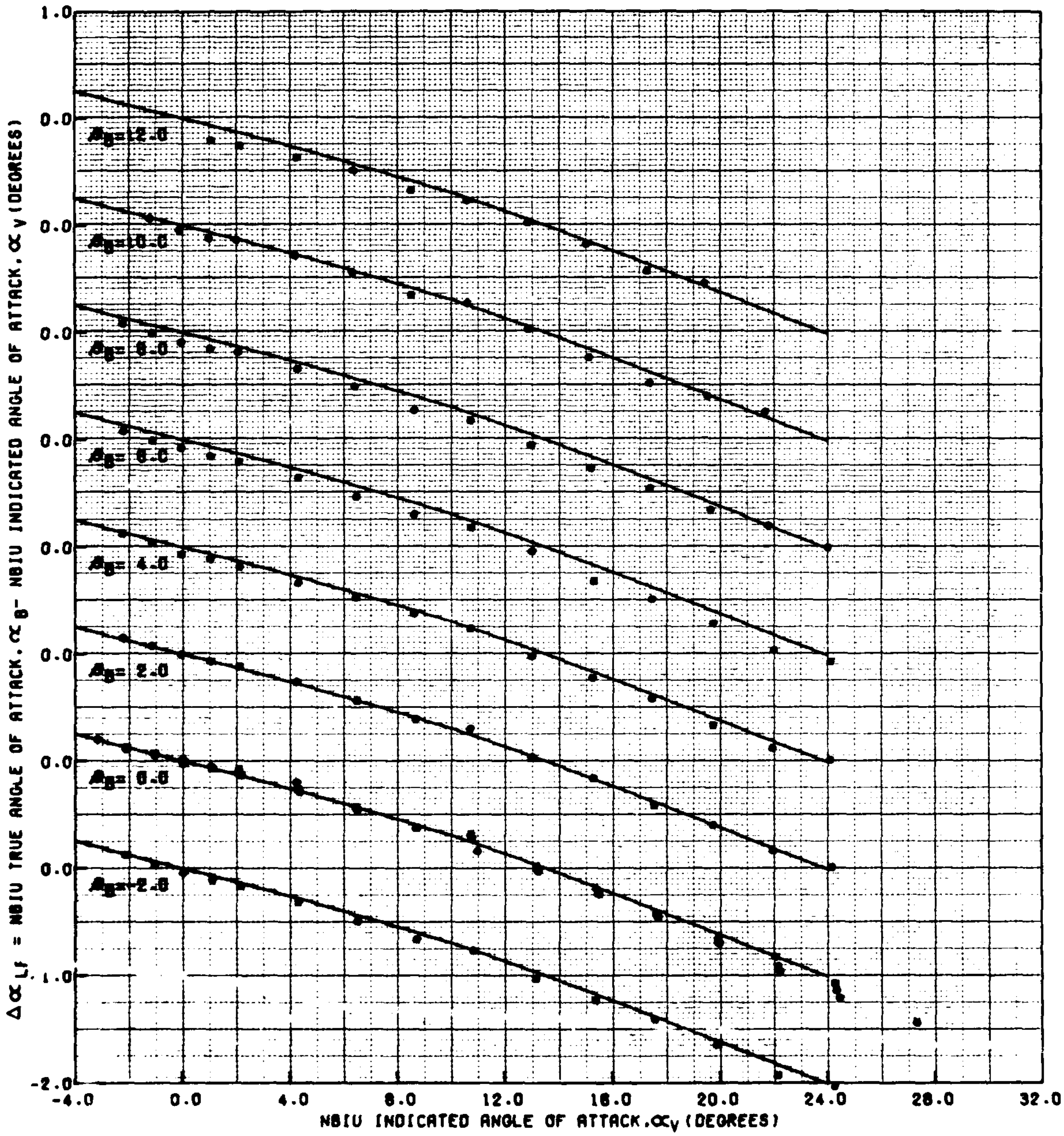


G) REFERENCE MACH NUMBER = 1.10
FIGURE A1: ANGLE OF ATTACK ERROR DUE TO LOCAL FLOW (CONTINUED)

AFFTC NBIU CALIBRATION
NASA/ARC 11- X 11-FOOT TUNNEL
TEST 11/97-731 - 1 MAY 1973

NOTES:
1. ACTUAL MACH NUMBER IS 1.20.
2. DATA HAS BEEN CORRECTED FOR 0.025 BIAS.

SYMBOL	EXPLANATION
⊙	$R_E/L = 3.1 \times 10^6$ (/FOOT)
——	AFFTC CURVE



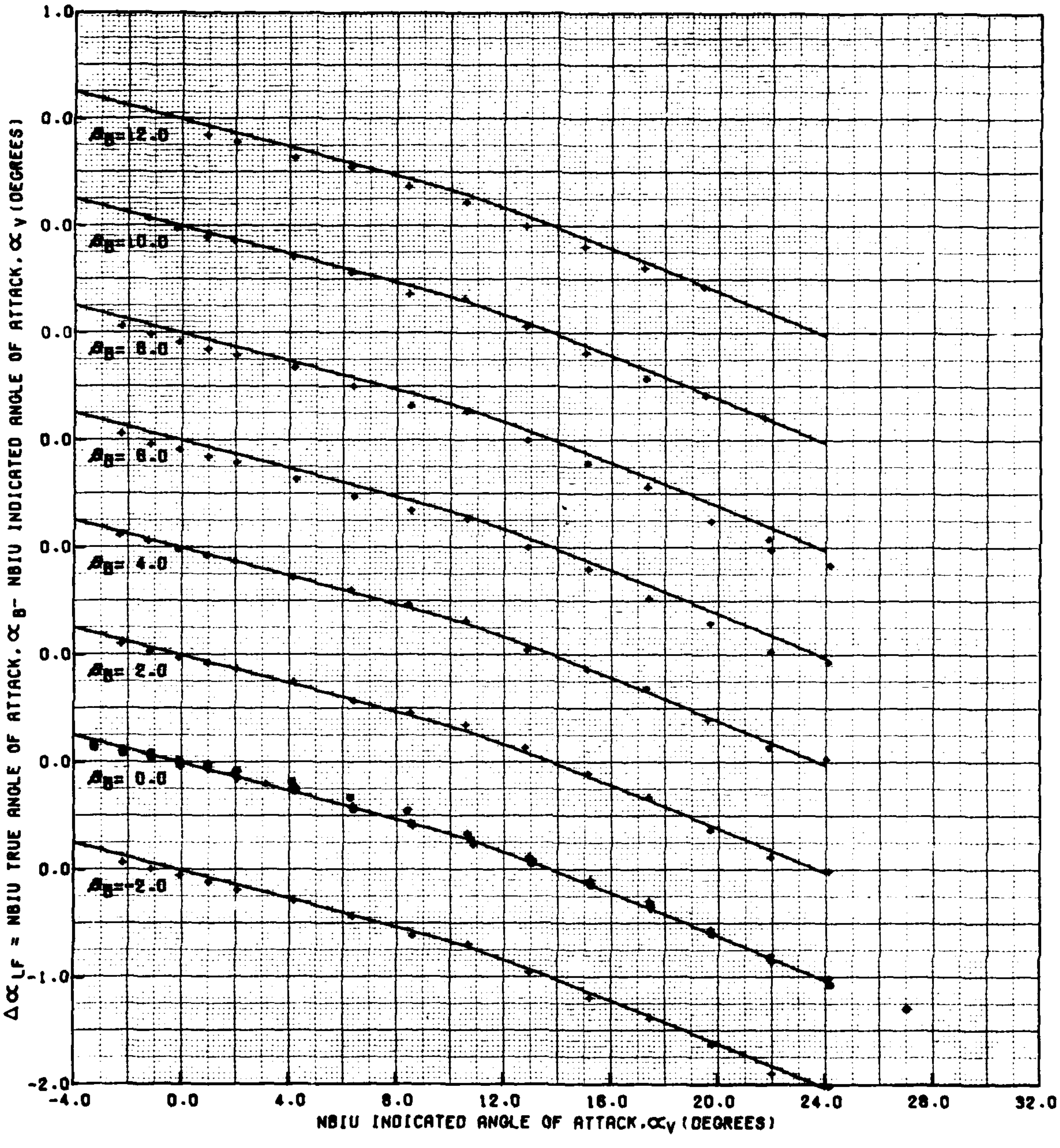
H) REFERENCE MACH NUMBER = 1.20

FIGURE A1: ANGLE OF ATTACK ERROR DUE TO LOCAL FLOW (CONTINUED)

AFFTC NBIU CALIBRATION
NASA/ARC 11- X 11-FOOT TUNNEL
TEST 11/97-731 - 1 MAY 1973

NOTES:
1. ACTUAL MACH NUMBER IS 1.30.
2. DATA HAS BEEN CORRECTED FOR 0.025 BIAS.

SYMBOL	EXPLANATION
⊙	$R_E/L = 2.4 \times 10^6$ (/FOOT)
+	$R_E/L = 3.7 \times 10^6$ (/FOOT)
——	AFFTC CURVE

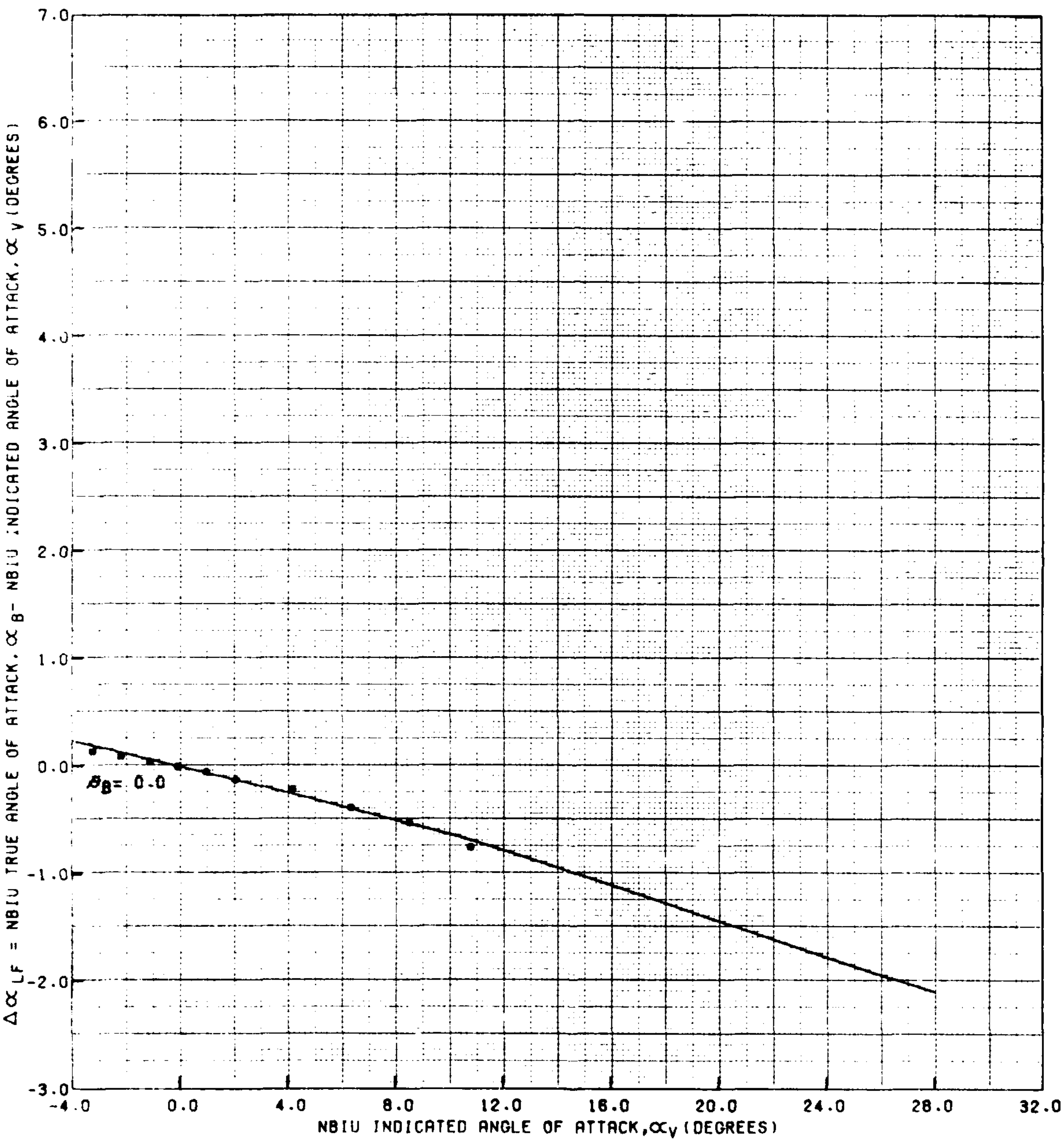


I) REFERENCE MACH NUMBER = 1.30
FIGURE A1: ANGLE OF ATTACK ERROR DUE TO LOCAL FLOW (CONTINUED)

AFFTC NBIU CALIBRATION
NASA/ARC 11- X 11-FOOT TUNNEL
TEST 11/97-731 - 1 MAY 1973

SYMBOL	EXPLANATION
⊙	$R_E/L = 4.1 \times 10^6$ (/FOOT)
——	AFFTC CURVE

NOTES:
1. ACTUAL MACH NUMBER IS 1.40.
2. DATA HAS BEEN CORRECTED FOR 0.025 BIAS.

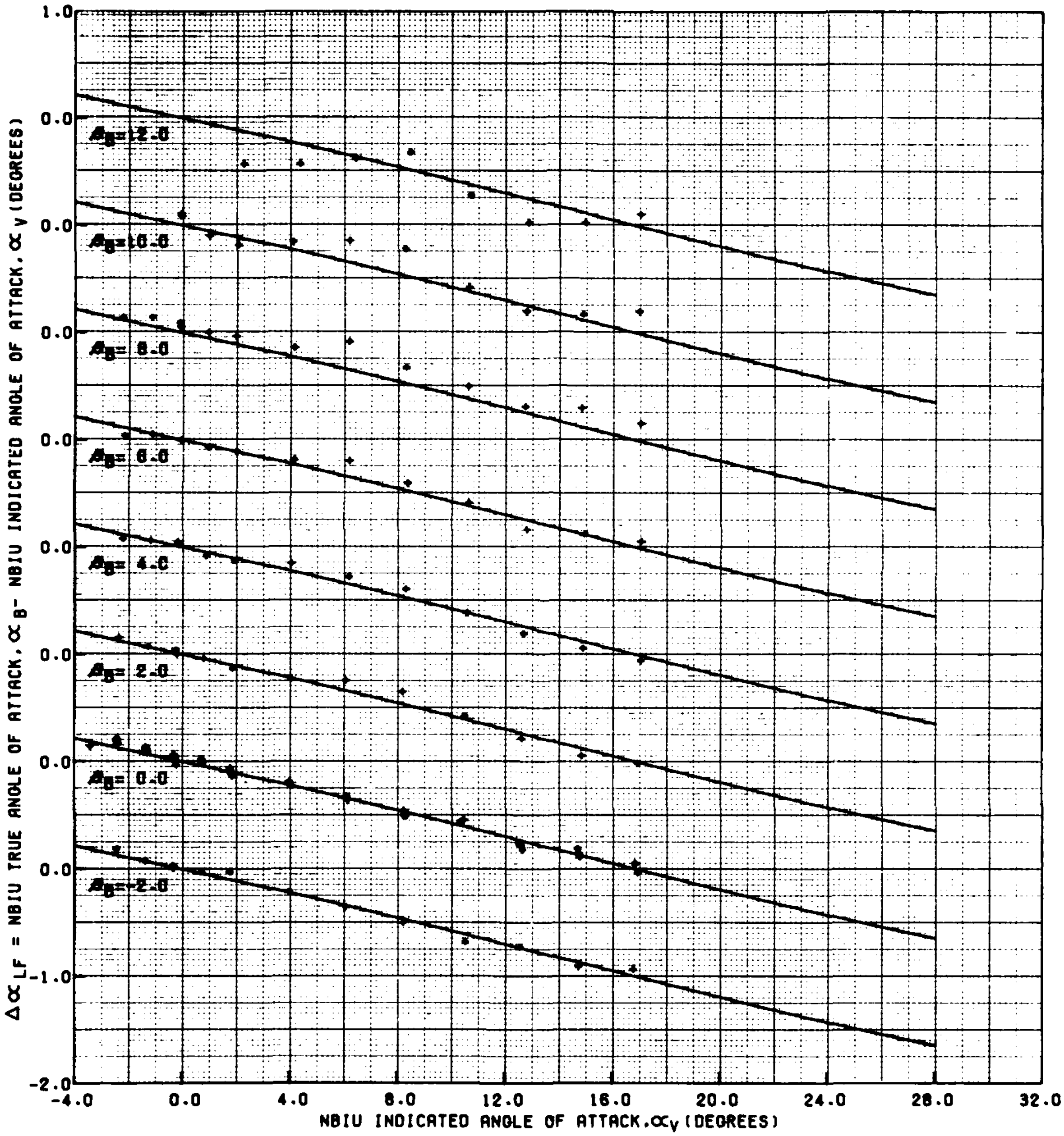


J) REFERENCE MACH NUMBER = 1.40
FIGURE A1: ANGLE OF ATTACK ERROR DUE TO LOCAL FLOW (CONTINUED)

AFFTC NBIU CALIBRATION
NASA/ARC 9- X 7-FOOT TUNNEL
TEST 11/97-731 - 1 MAY 1973

NOTES:
1. ACTUAL MACH NUMBER IS 1.55.
2. DATA HAS BEEN CORRECTED FOR 0.095 BIAS.

SYMBOL	EXPLANATION
○	$R_E/L = 2.0 \times 10^6$ (/FOOT)
+	$R_E/L = 4.0 \times 10^6$ (/FOOT)
——	AFFTC CURVE



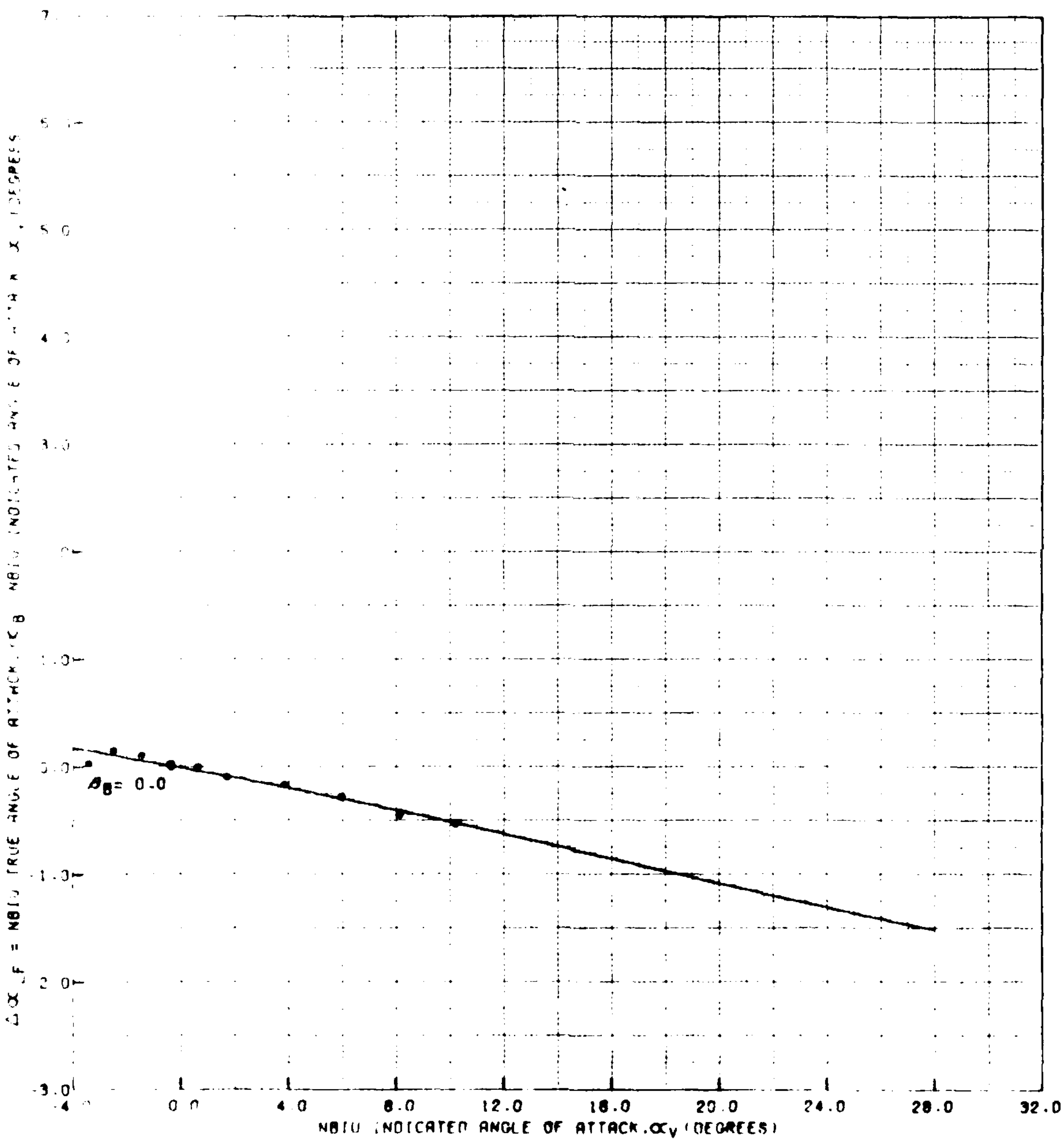
K) REFERENCE MACH NUMBER = 1.51

FIGURE A1: ANGLE OF ATTACK ERROR DUE TO LOCAL FLOW (CONTINUED)

AFFTC NBIU CALIBRATION
NASA/ARC 9- X 7-FOOT TUNNEL
TEST 11/97-731 - 1 MAY 1973

SYMBOL	EXPLANATION
ʘ	R_E/L = 3.7X10[6](/FOOT)
----	AFFTC CURVE

NOTES:
1. ACTUAL MACH NUMBER IS 1.72.
2. DATA HAS BEEN CORRECTED FOR 0.095 BIAS.

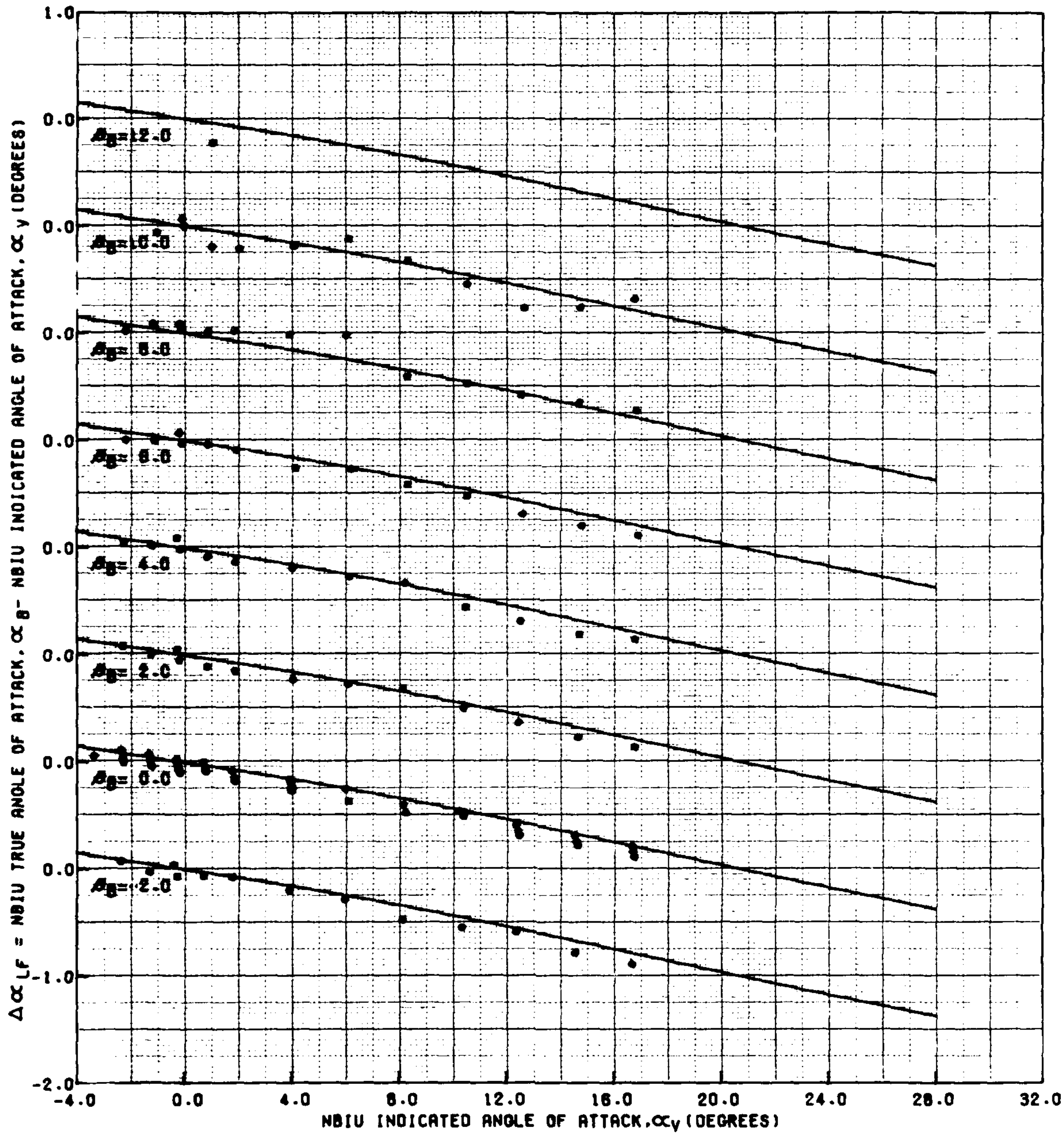


(i) REFERENCE MACH NUMBER = 1.71
FIGURE A1: ANGLE OF ATTACK ERROR DUE TO LOCAL FLOW (CONTINUED)

AFFTC NBIU CALIBRATION
NASA/ARC 9- X 7-FOOT TUNNEL
TEST 11/97-731 - 1 MAY 1973

SYMBOL	EXPLANATION
⊙	$R_E/L = 4.3 \times 10^6$ (/FOOT)
——	AFFTC CURVE

NOTES:
1. ACTUAL MACH NUMBER IS 1.88.
2. DATA HAS BEEN CORRECTED FOR 0.095 BIAS.

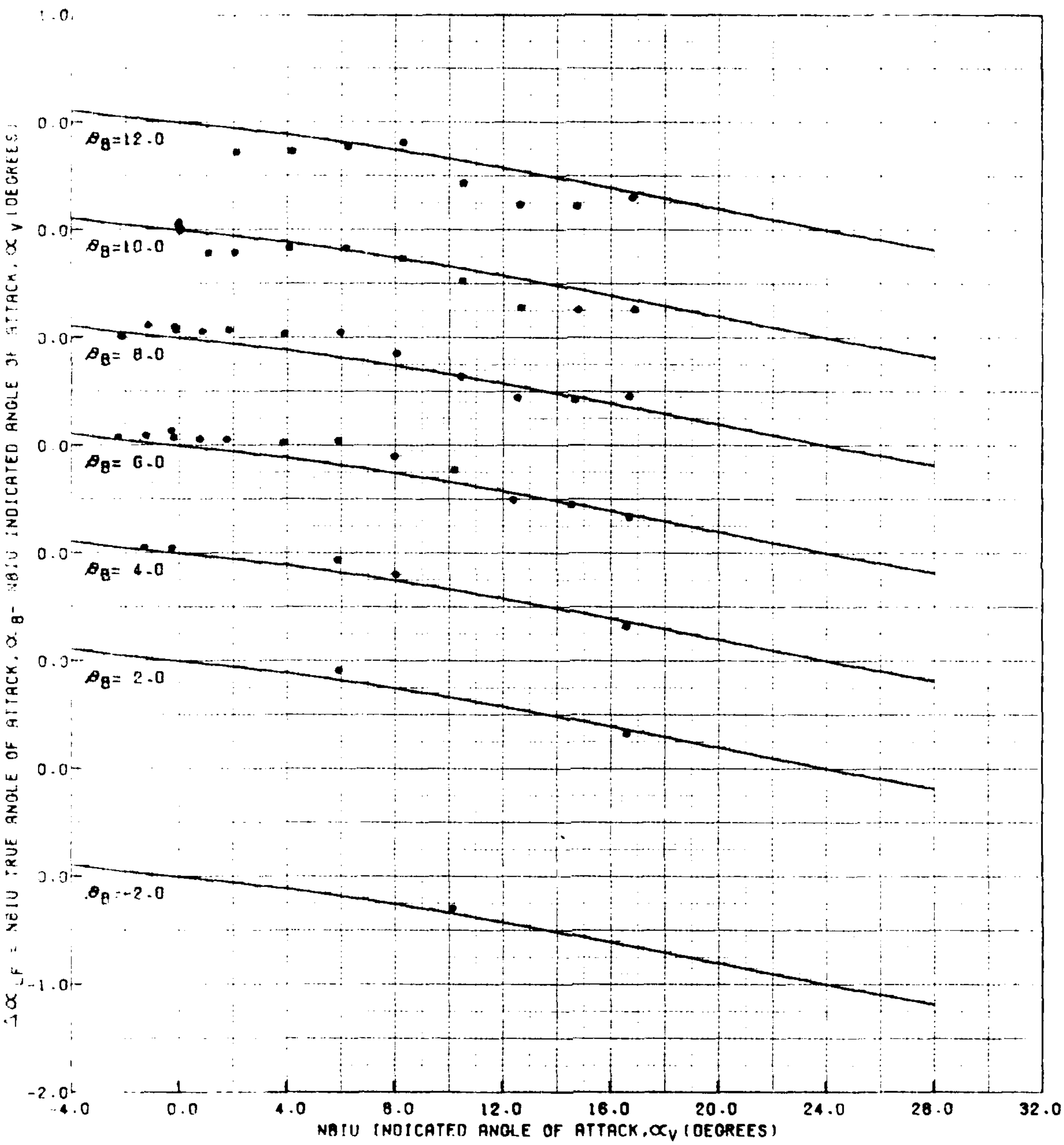


M) REFERENCE MACH NUMBER = 1.91
FIGURE A1: ANGLE OF ATTACK ERROR DUE TO LOCAL FLOW (CONTINUED)

AFFTC NBIU CALIBRATION
NASA/ARC 9- X 7-FOOT TUNNEL
TEST 11/97-731 - 1 MAY 1973

SYMBOL	EXPLANATION
⊙	R_E/L = 4.2X10^6(/FOOT)
— -	AFFTC CURVE

NOTES:
1. ACTUAL MACH NUMBER IS 2.07.
2. DATA HAS BEEN CORRECTED FOR 0.095 BIAS.



N) REFERENCE MACH NUMBER = 2.11

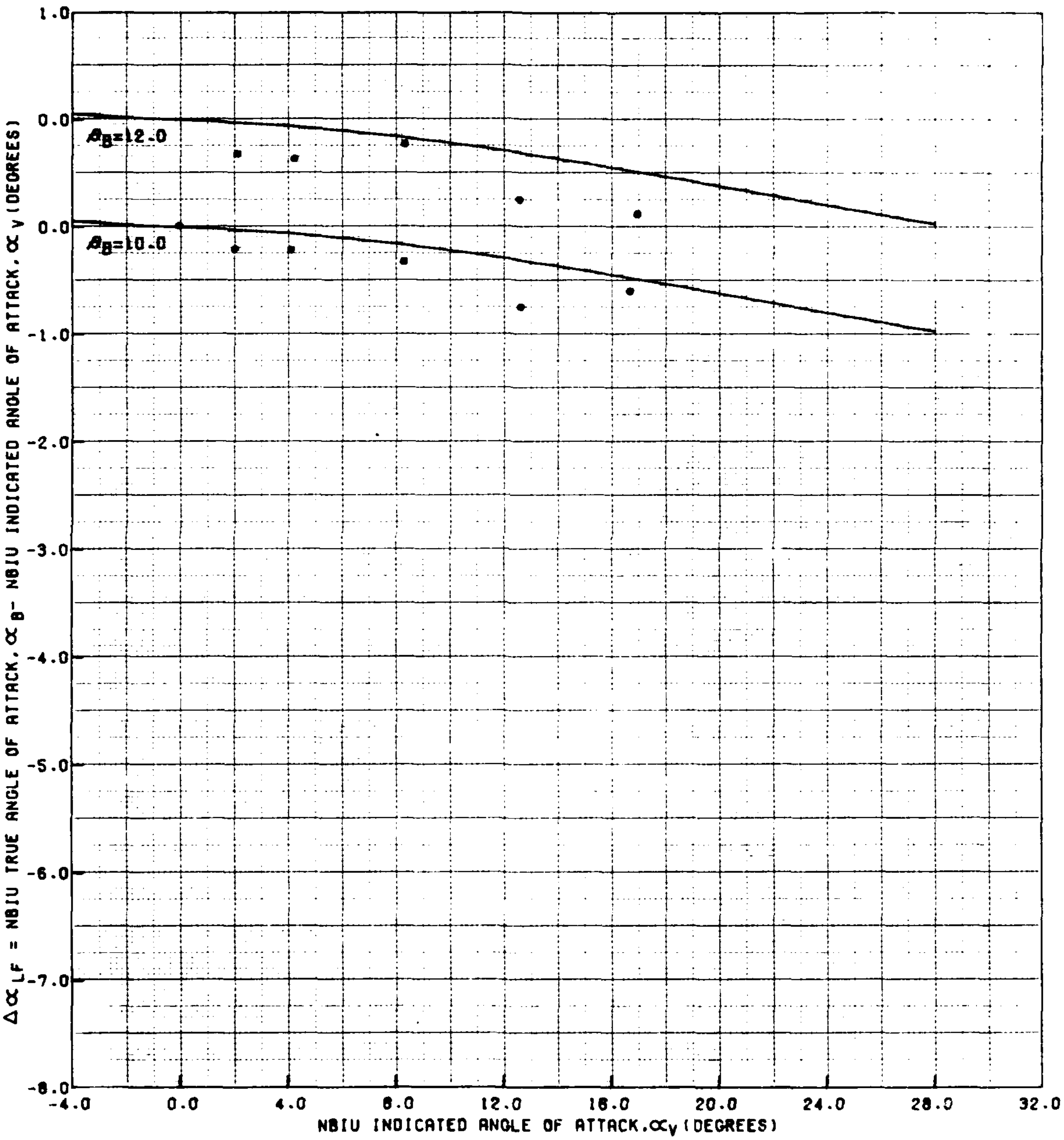
FIGURE A1: ANGLE OF ATTACK ERROR DUE TO LOCAL FLOW (CONTINUED)

AFFTC NBIU CALIBRATION

NASA/ARC 9- X 7-FOOT TUNNEL
TEST 11/97-731 - 1 MAY 1973

NOTES:
1. ACTUAL MACH NUMBER IS 2.27.
2. DATA HAS BEEN CORRECTED FOR 0.095 BIAS.

SYMBOL	EXPLANATION
⊙	$R_E/L = 4.1 \times 10^6$ (/FOOT)
——	AFFTC CURVE

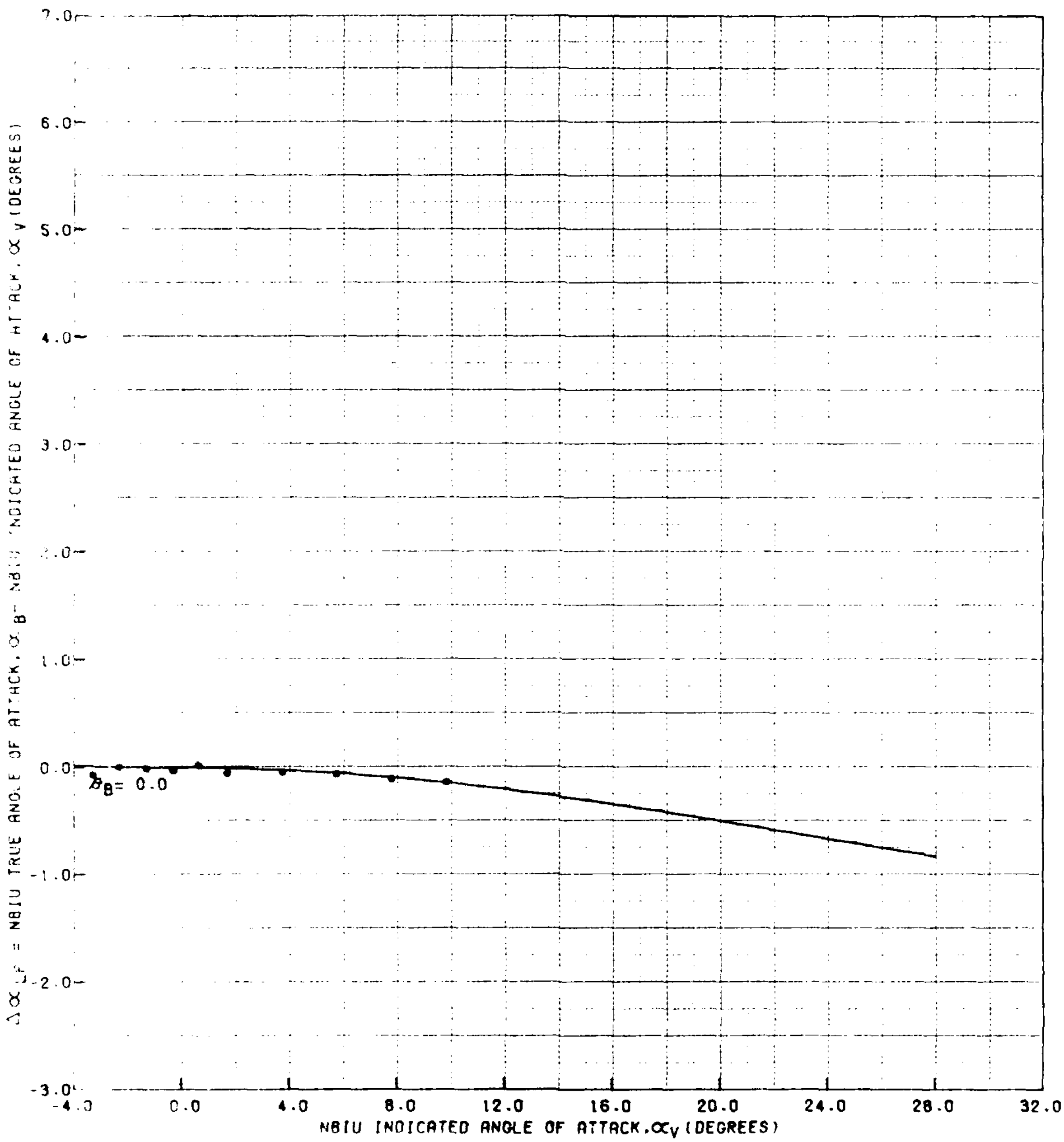


O) REFERENCE MACH NUMBER = 2.31
FIGURE A1: ANGLE OF ATTACK ERROR DUE TO LOCAL FLOW (CONTINUED)

AFFTC NBIU CALIBRATION
NASA/ARC 9- X 7-FOOT TUNNEL
TEST '1/97-731 - 1 MAY 1973

NOTES:
1. ACTUAL MACH NUMBER IS 2.39.
2. DATA HAS BEEN CORRECTED FOR 0.095 BIAS.

SYMBOL	EXPLANATION
⊙	$R_E/L = 3.7\times10^6$ (/FOOT)
——	AFFTC CURVE

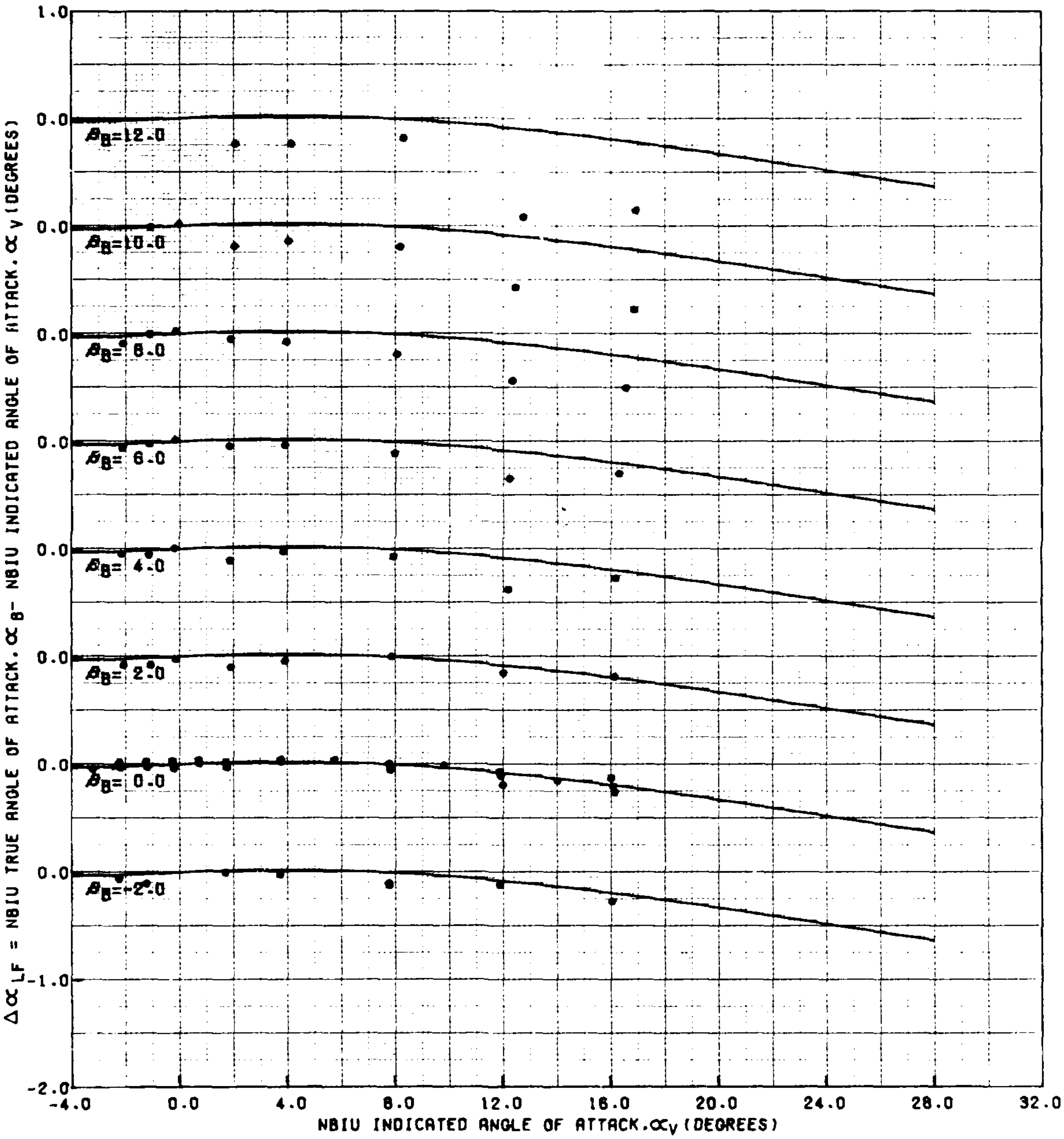


P) REFERENCE MACH NUMBER = 2.41
FIGURE A1: ANGLE OF ATTACK ERROR DUE TO LOCAL FLOW (CONTINUED)

AFFTC NBIU CALIBRATION
NASA/ARC 9- X 7-FOOT TUNNEL
TEST 11/97-731 - 1 MAY 1973

NOTES:
1. ACTUAL MACH NUMBER IS 2.55.
2. DATA HAS BEEN CORRECTED FOR 0.095 BIAS.

SYMBOL	EXPLANATION
⊙	$R_E/L = 3.6 \times 10^6$ (/FOOT)
——	AFFTC CURVE



Q) REFERENCE MACH NUMBER = 2.54
FIGURE A1: ANGLE OF ATTACK ERROR DUE TO LOCAL FLOW (CONCLUDED)

APPENDIX B

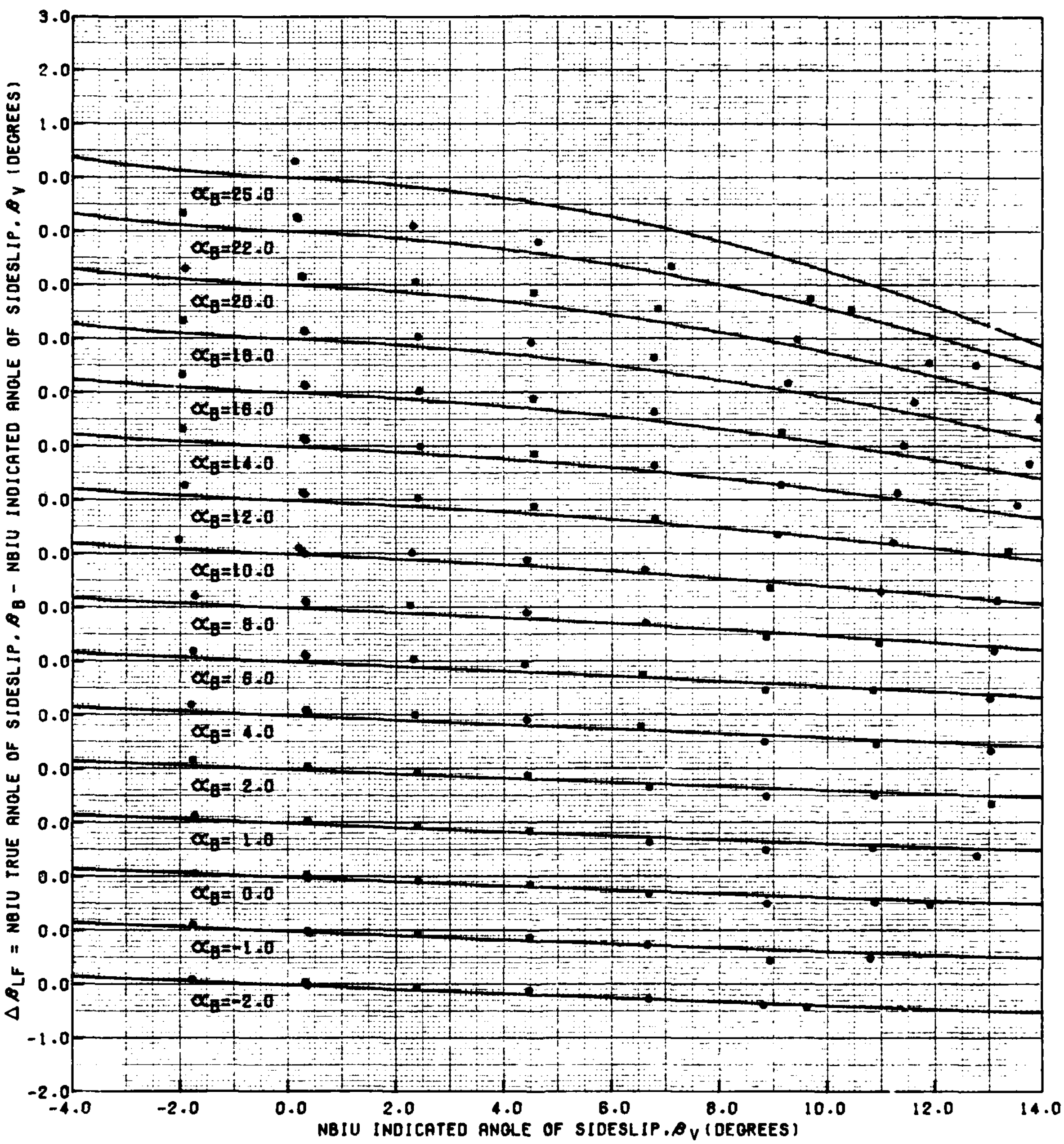
COMPARISON OF ANGLE-OF-SIDESLIP DATA AND FAIRINGS

Data from the NASA/ARC calibration of the AFFTC NBIU were plotted on the same grid as the AFFTC fairing. The data from test 11/97-731 were first corrected as described in the body of this memorandum and plotted. The AFFTC fairing as obtained from the production software was also plotted. Figure B1 presents the error in angle of sideslip due to local flow for all test Mach numbers and angles of attack for a range of indicated angles of sideslip.

AFFTC NBIU CALIBRATION
NASA/ARC 11- X 11-FOOT TUNNEL
TEST 11/97-731 - 1 MAY 1973

NOTES:
1. ACTUAL MACH NUMBER IS 0.40.
2. DATA HAS BEEN CORRECTED FOR -.285 BIAS.

SYMBOL	EXPLANATION
⊙	$R_E/L = 2.0 \times 10^6$ (/FOOT)
——	AFFTC CURVE

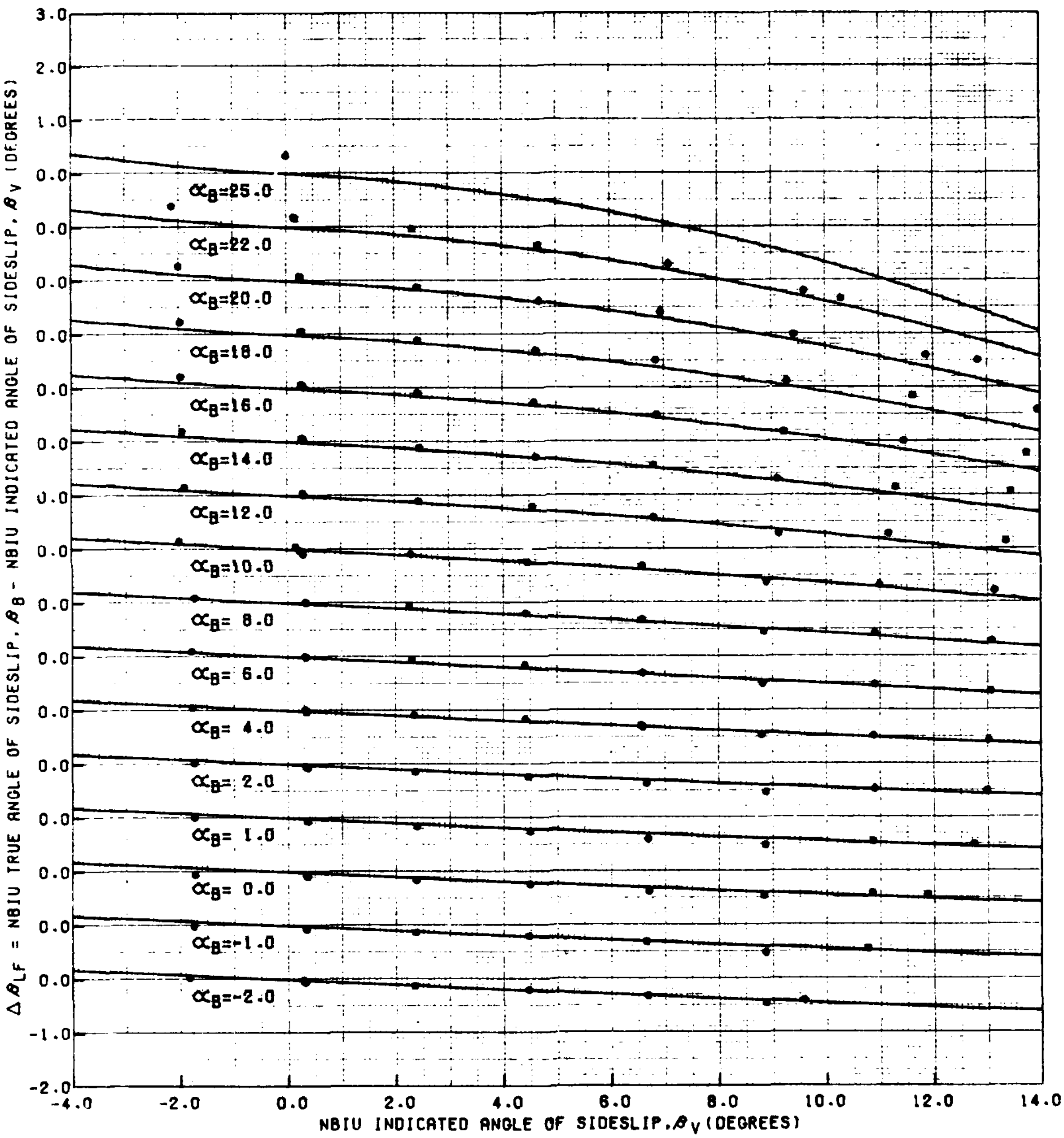


A) REFERENCE MACH NUMBER = 0.40
FIGURE B1: ANGLE OF SIDESLIP ERROR DUE TO LOCAL FLOW

AFFTC NBIU CALIBRATION
NASA/ARC 11- X 11-FOOT TUNNEL
TEST 11/97-731 - 1 MAY 1973

NOTES:
1. ACTUAL MACH NUMBER IS 0.60.
2. DATA HAS BEEN CORRECTED FOR -.285 BIAS.

SYMBOL	EXPLANATION
⊙	$R_E/L = 2.6\times10^6$ (/FOOT)
——	AFFTC CURVE

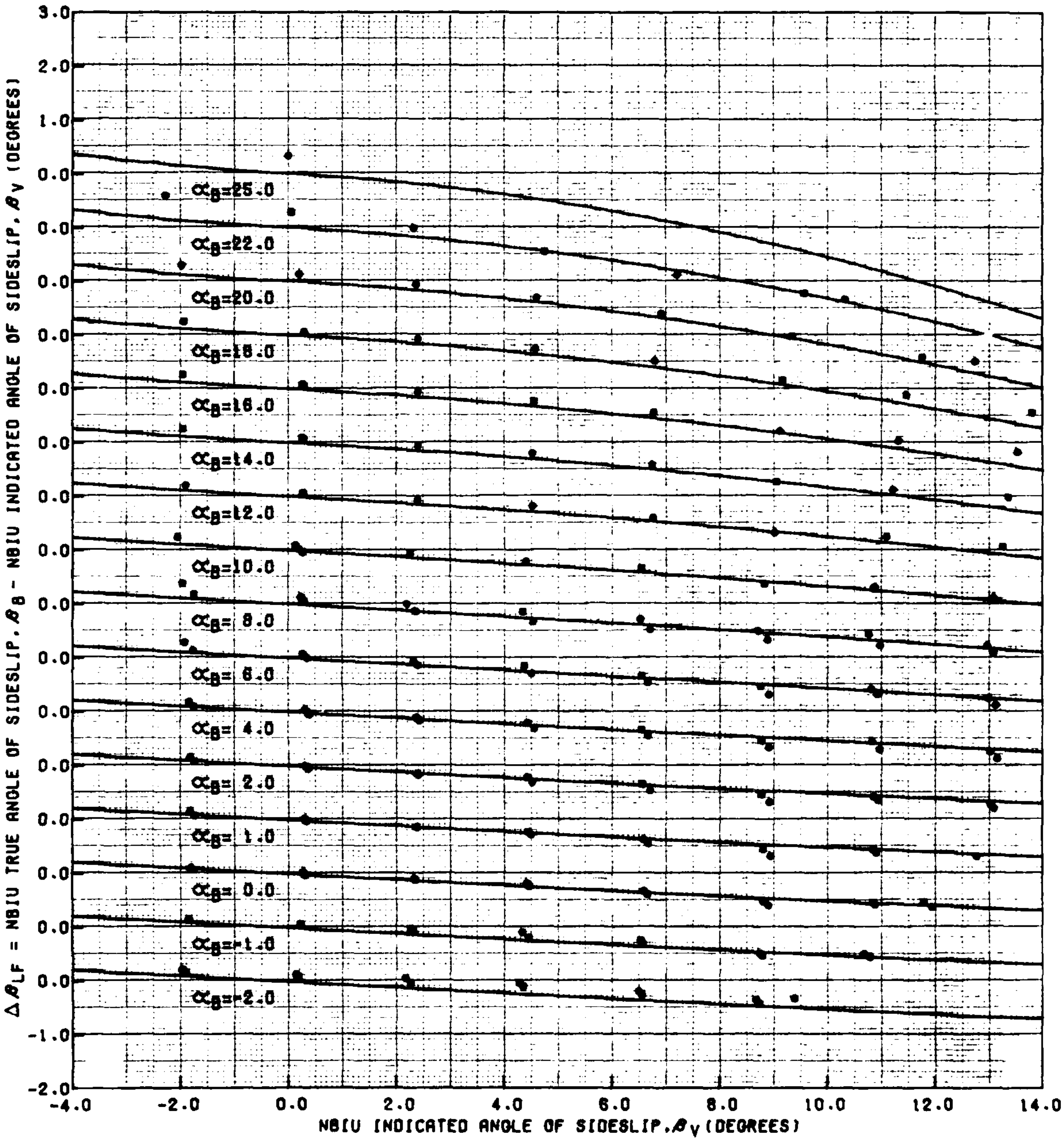


B) REFERENCE MACH NUMBER = 0.60
FIGURE B1: ANGLE OF SIDESLIP ERROR DUE TO LOCAL FLOW (CONTINUED)

AFFTC NBIU CALIBRATION
NASA/ARC 11- X 11-FOOT TUNNEL
TEST 11/97-731 - 1 MAY 1973

NOTES:
1. ACTUAL MACH NUMBER IS 0.80.
2. DATA HAS BEEN CORRECTED FOR -.285 BIAS.

SYMBOL	EXPLANATION
⊙	$R_E/L = 2.1 \times 10^6$ (/FOOT)
——	AFFTC CURVE



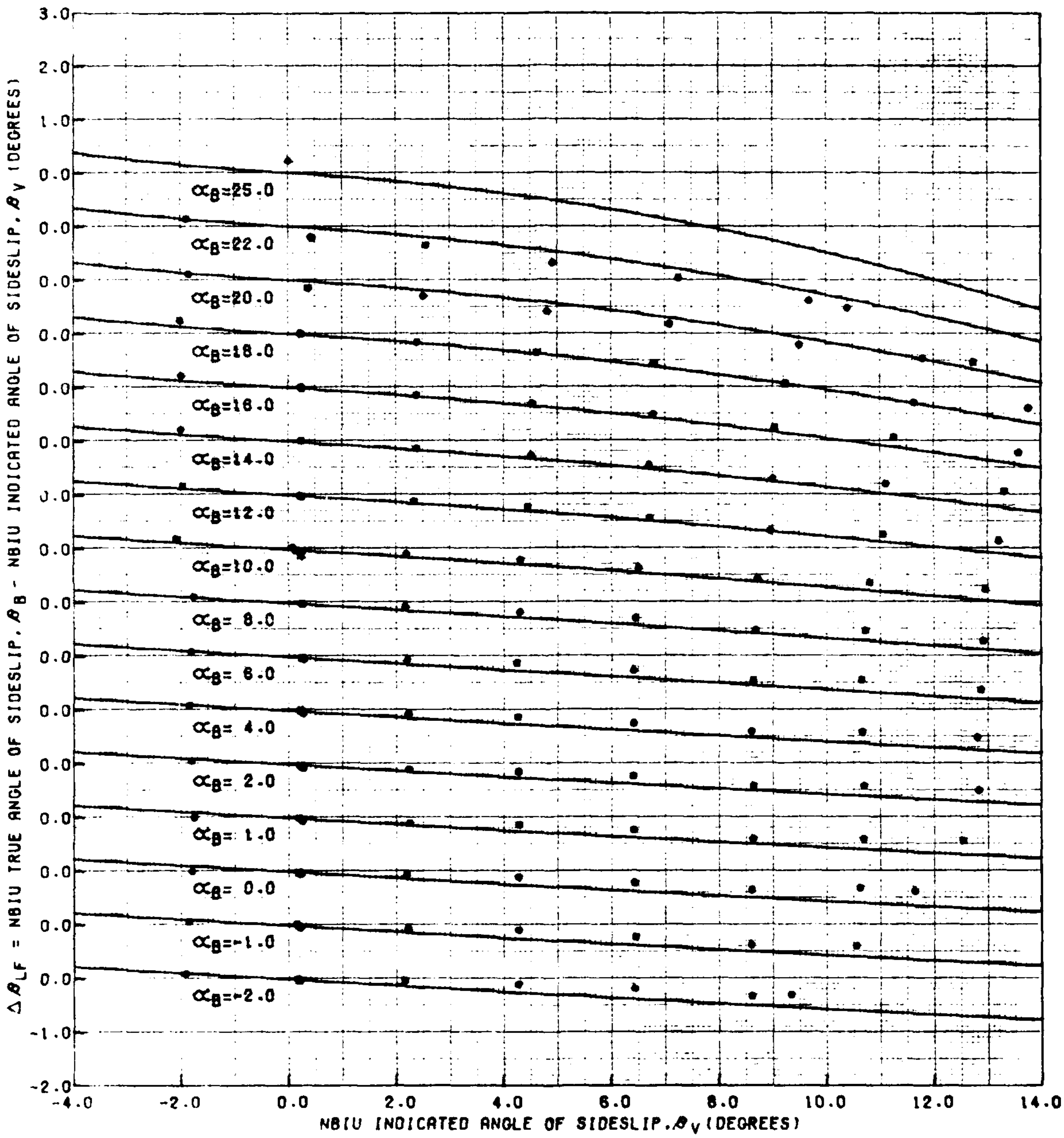
C) REFERENCE MACH NUMBER = 0.80

FIGURE B1: ANGLE OF SIDESLIP ERROR DUE TO LOCAL FLOW (CONTINUED)

AFFTC NBIU CALIBRATION
NASA/ARC 11- X 11-FOOT TUNNEL
TEST 11/97-731 - 1 MAY 1973

NOTES:
1. ACTUAL MACH NUMBER IS 0.90.
2. DATA HAS BEEN CORRECTED FOR -.285 BIAS.

SYMBOL	EXPLANATION
⊙	R_E/L = 2.0X10^6(/FOOT)
+	R_E/L = 3.3X10^6(/FOOT)
×	R_E/L = 5.5X10^6(/FOOT)
——	AFFTC CURVE

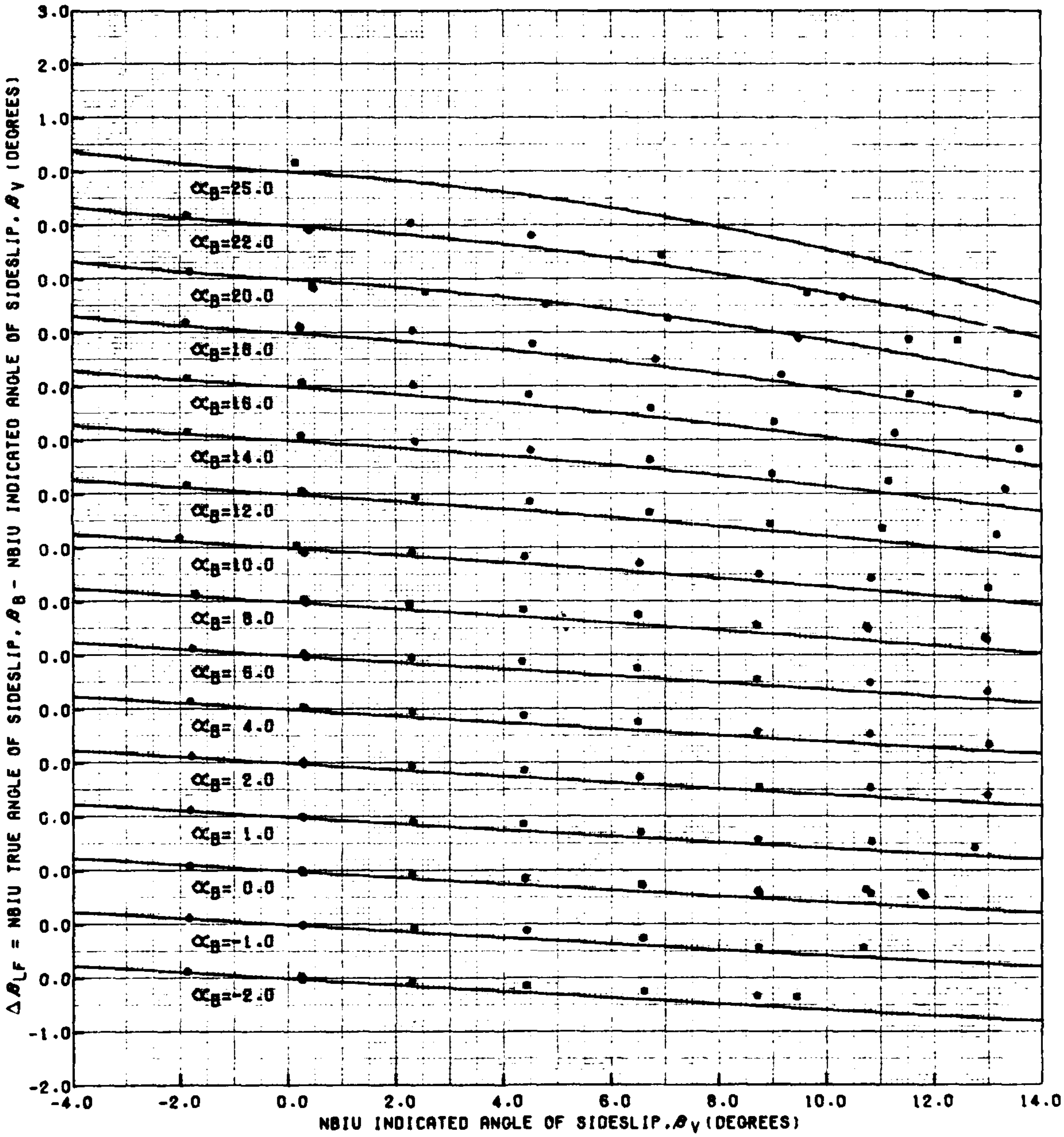


D) REFERENCE MACH NUMBER = 0.90
FIGURE B1: ANGLE OF SIDESLIP ERROR DUE TO LOCAL FLOW (CONTINUED)

AFFTC NBIU CALIBRATION
NASA/ARC 11- X 11-FOOT TUNNEL
TEST 11/97-731 - 1 MAY 1973

NOTES:
1. ACTUAL MACH NUMBER IS 0.95.
2. DATA HAS BEEN CORRECTED FOR -.285 BIAS.

SYMBOL	EXPLANATION
⊙	$R_E/L = 1.8 \times 10^6$ (/FOOT)
——	AFFTC CURVE

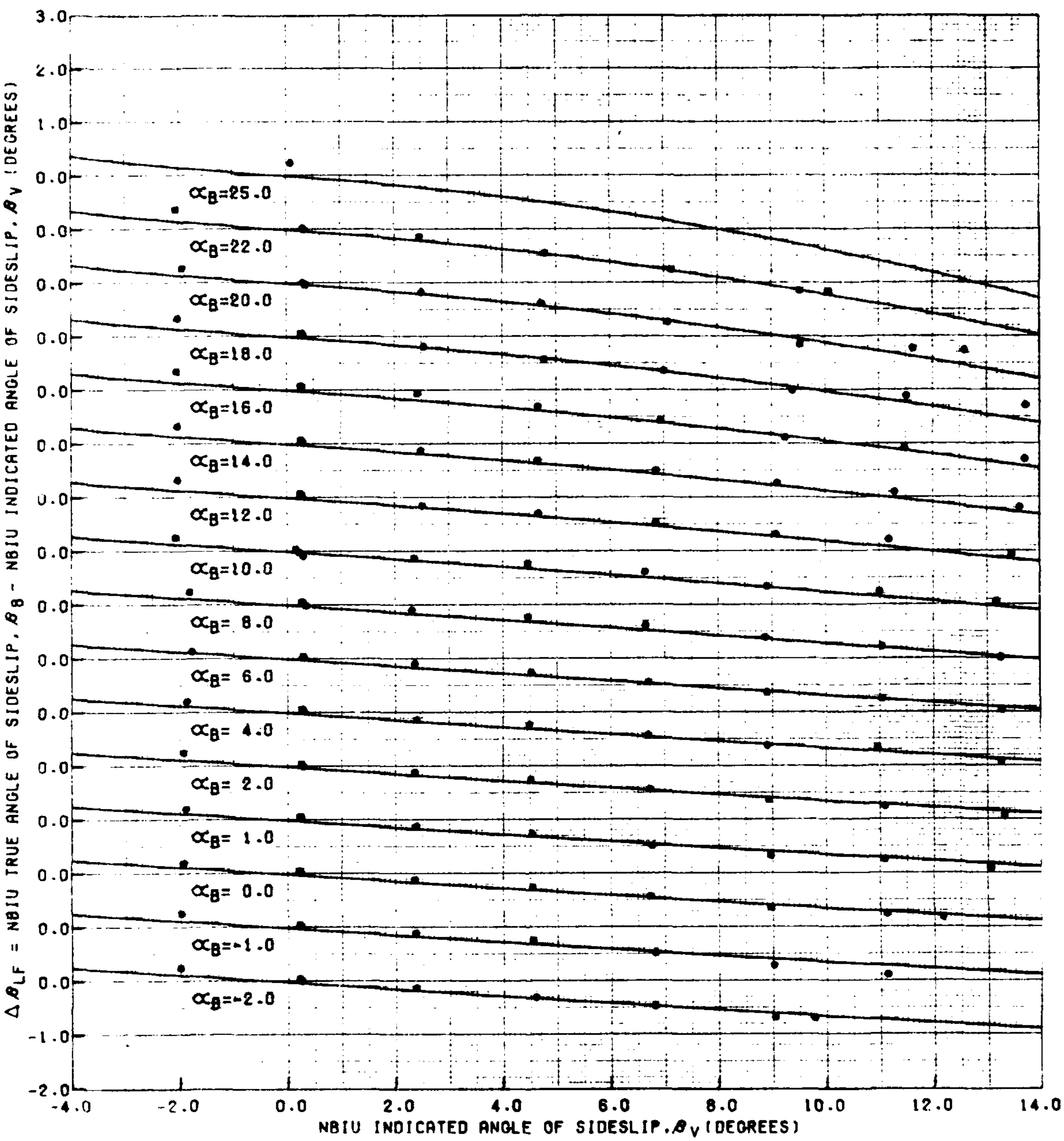


E) REFERENCE MACH NUMBER = 0.95
FIGURE B1: ANGLE OF SIDESLIP ERROR DUE TO LOCAL FLOW (CONTINUED)

AFFTC NBIU CALIBRATION
NASA/ARC 11- X 11-FOOT TUNNEL
TEST 11/97-731 - 1 MAY 1973

SYMBOL	EXPLANATION
⊙	$R_E/L = 2.8 \times 10^6$ (/FOOT)
— —	AFFTC CURVE

NOTES:
1. ACTUAL MACH NUMBER IS 1.05.
2. DATA HAS BEEN CORRECTED FOR -.285 BIAS.

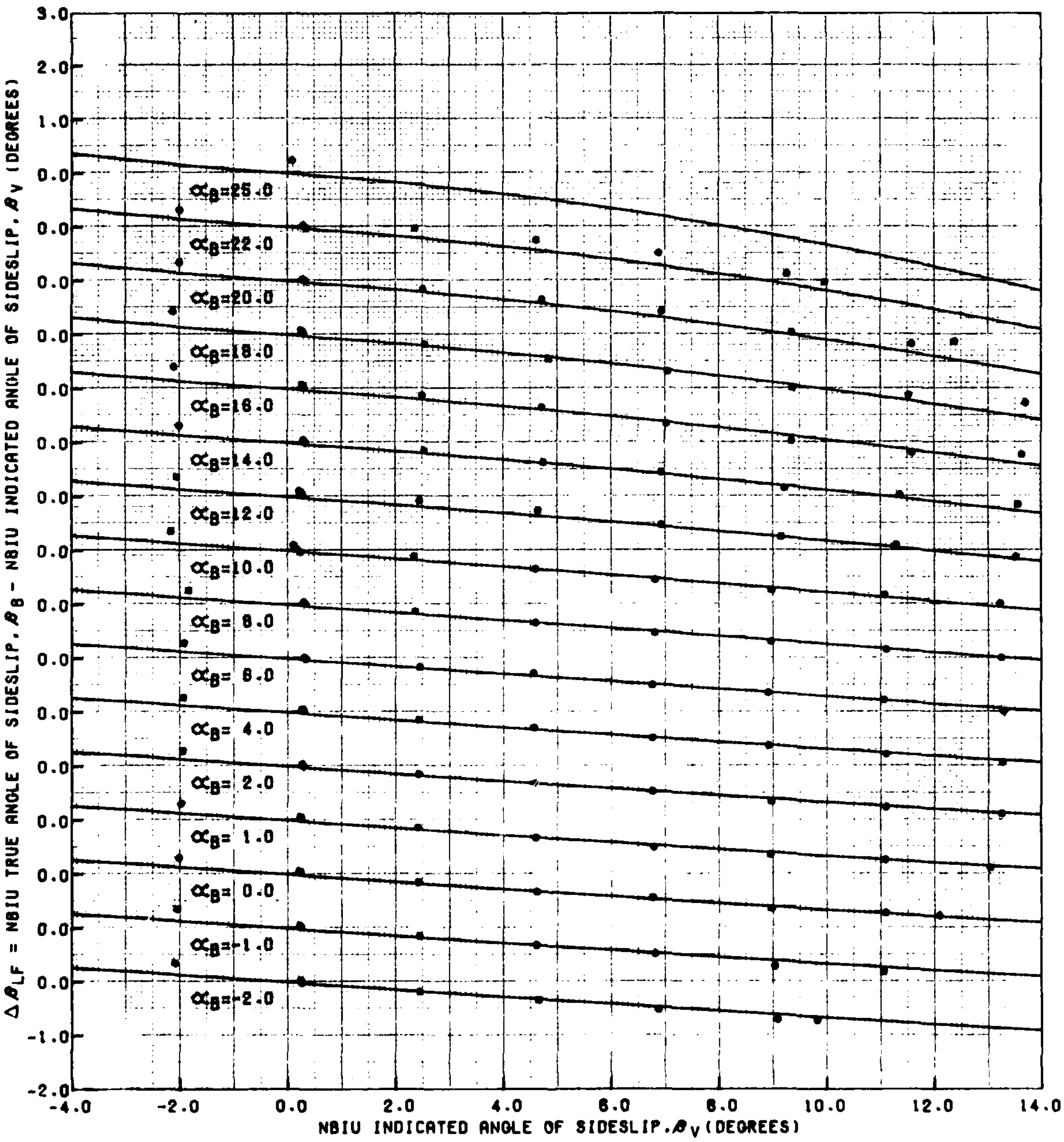


F) REFERENCE MACH NUMBER = 1.05
FIGURE B1: ANGLE OF SIDESLIP ERROR DUE TO LOCAL FLOW (CONTINUED)

AFFTC NBIU CALIBRATION
NASA/ARC 11- X 11-FOOT TUNNEL
TEST 11/97-731 - 1 MAY 1973

SYMBOL	EXPLANATION
⊙	$R_E/L = 2.9 \times 10^6$ (/FOOT)
——	AFFTC CURVE

NOTES:
1. ACTUAL MACH NUMBER IS 1.10.
2. DATA HAS BEEN CORRECTED FOR -.285 BIAS.

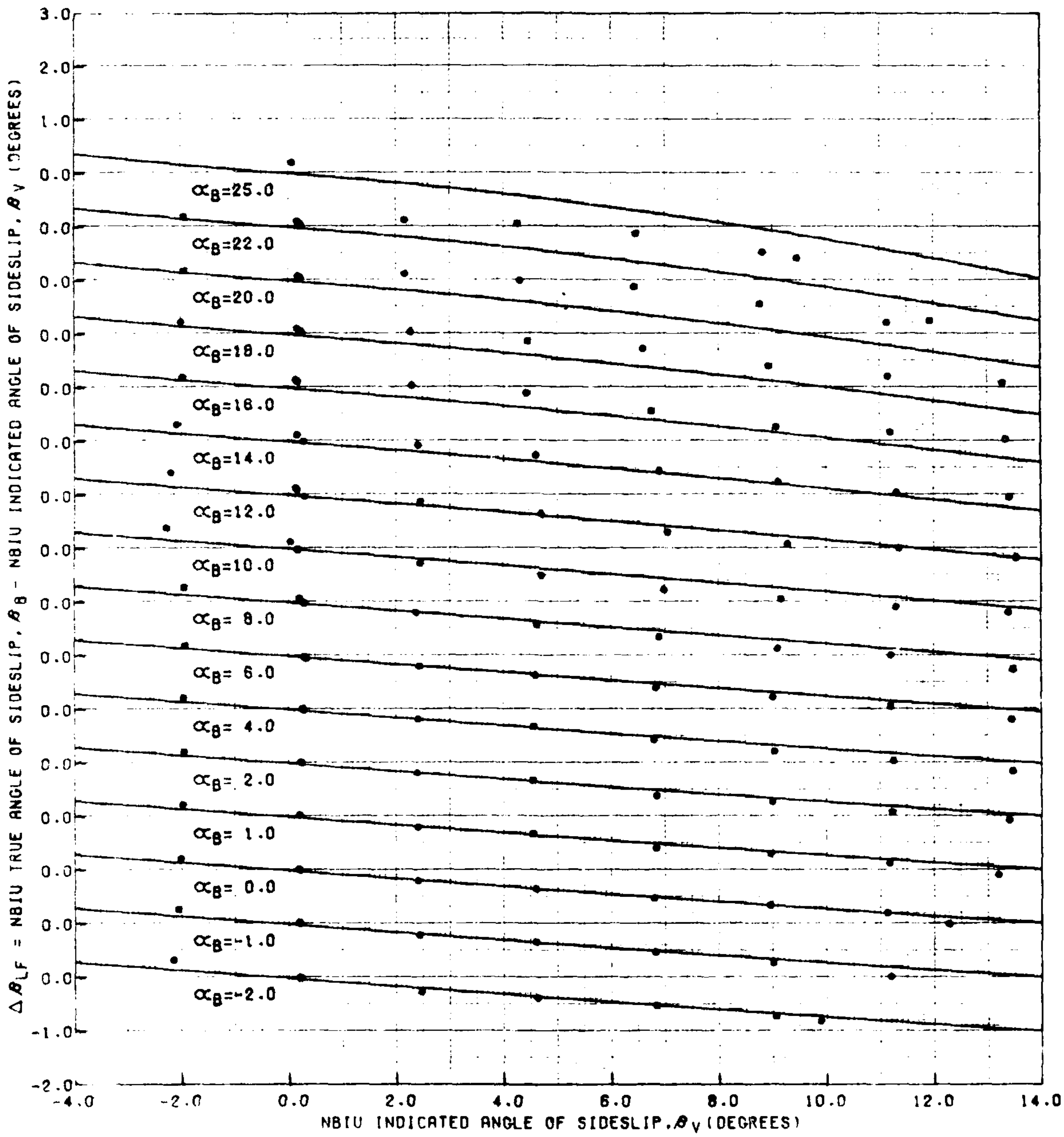


G) REFERENCE MACH NUMBER = 1.10
FIGURE B1: ANGLE OF SIDESLIP ERROR DUE TO LOCAL FLOW (CONTINUED)

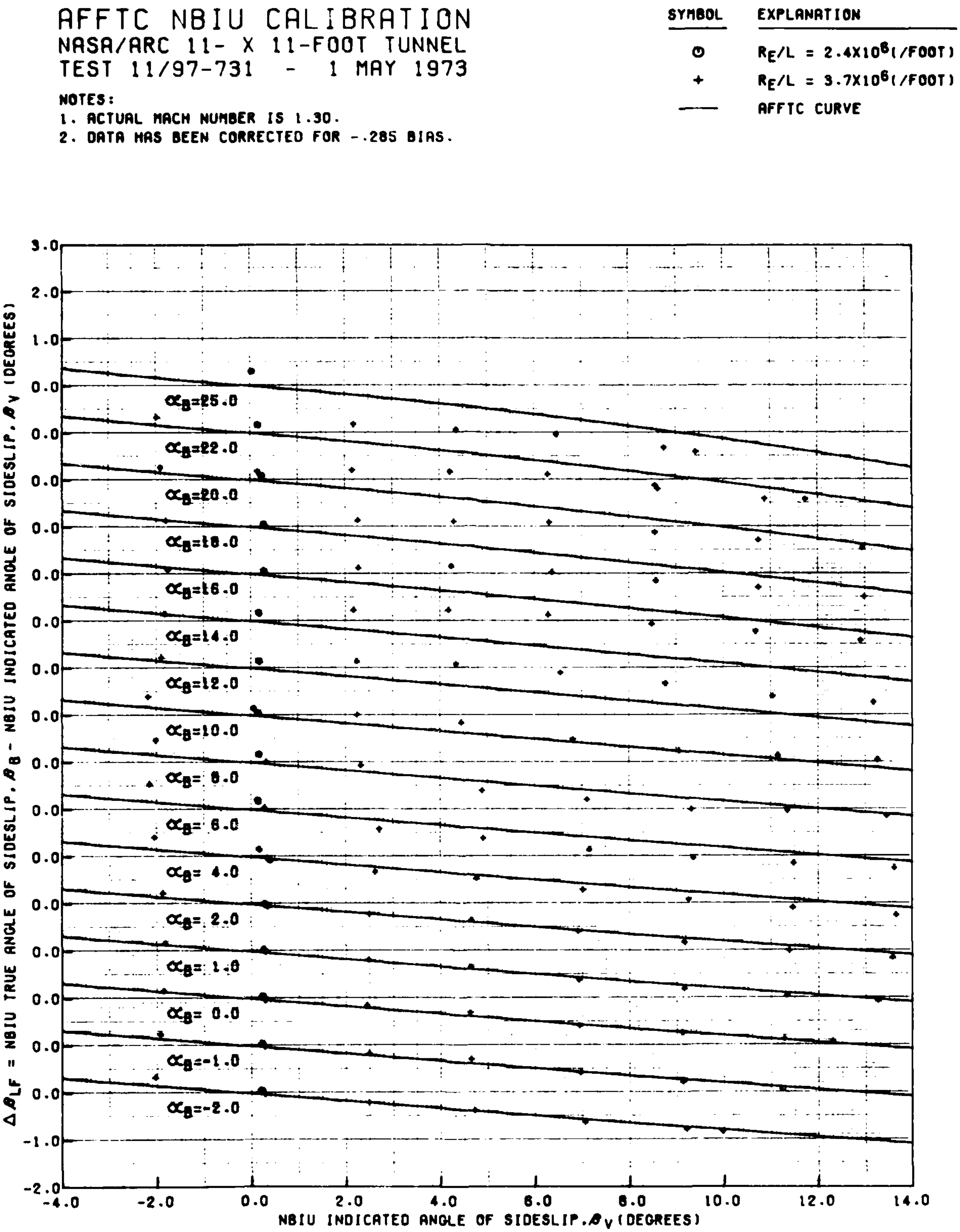
AFFTC NBIU CALIBRATION
NASA/ARC 11- X 11-FOOT TUNNEL
TEST 11/97-731 - 1 MAY 1973

NOTES:
1. ACTUAL MACH NUMBER IS 1.20.
2. DATA HAS BEEN CORRECTED FOR -.285 BIAS.

SYMBOL	EXPLANATION
⊙	$R_E/L = 3.1 \times 10^6$ (/FOOT)
——	AFFTC CURVE



H) REFERENCE MACH NUMBER = 1.20
FIGURE B1: ANGLE OF SIDESLIP ERROR DUE TO LOCAL FLOW (CONTINUED)



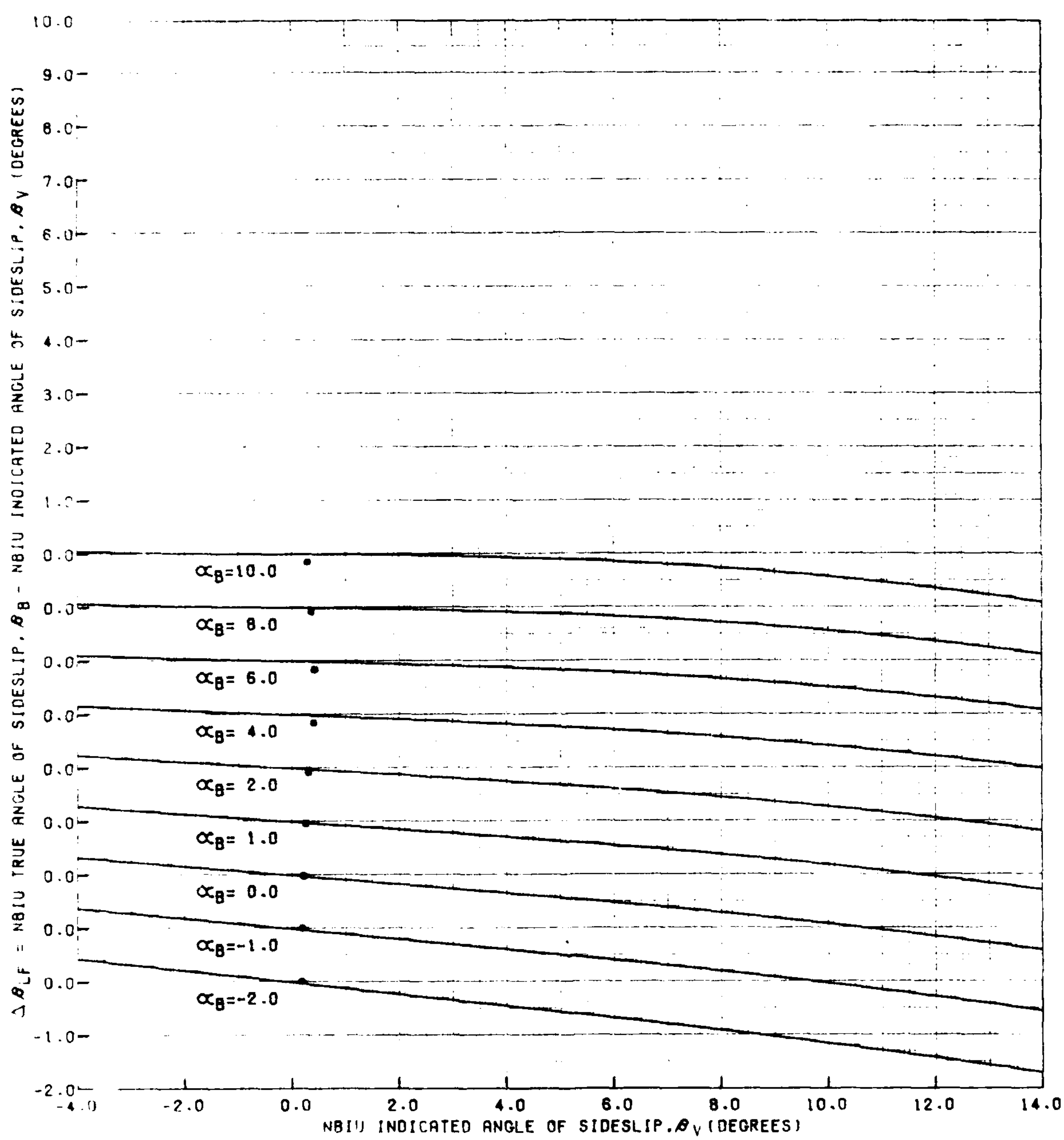
I) REFERENCE MACH NUMBER = 1.30

FIGURE B1: ANGLE OF SIDESLIP ERROR DUE TO LOCAL FLOW (CONTINUED)

AFFTC NBIU CALIBRATION
NASA/ARC 11- X 11-FOOT TUNNEL
TEST 11/97-731 - 1 MAY 1973

NOTES:
1. ACTUAL MACH NUMBER IS 1.40.
2. DATA HAS BEEN CORRECTED FOR -.285 BIAS.

SYMBOL	EXPLANATION
⊙	$R_E/L = 4.1X10^6$(/FOOT)
— - —	AFFTC CURVE

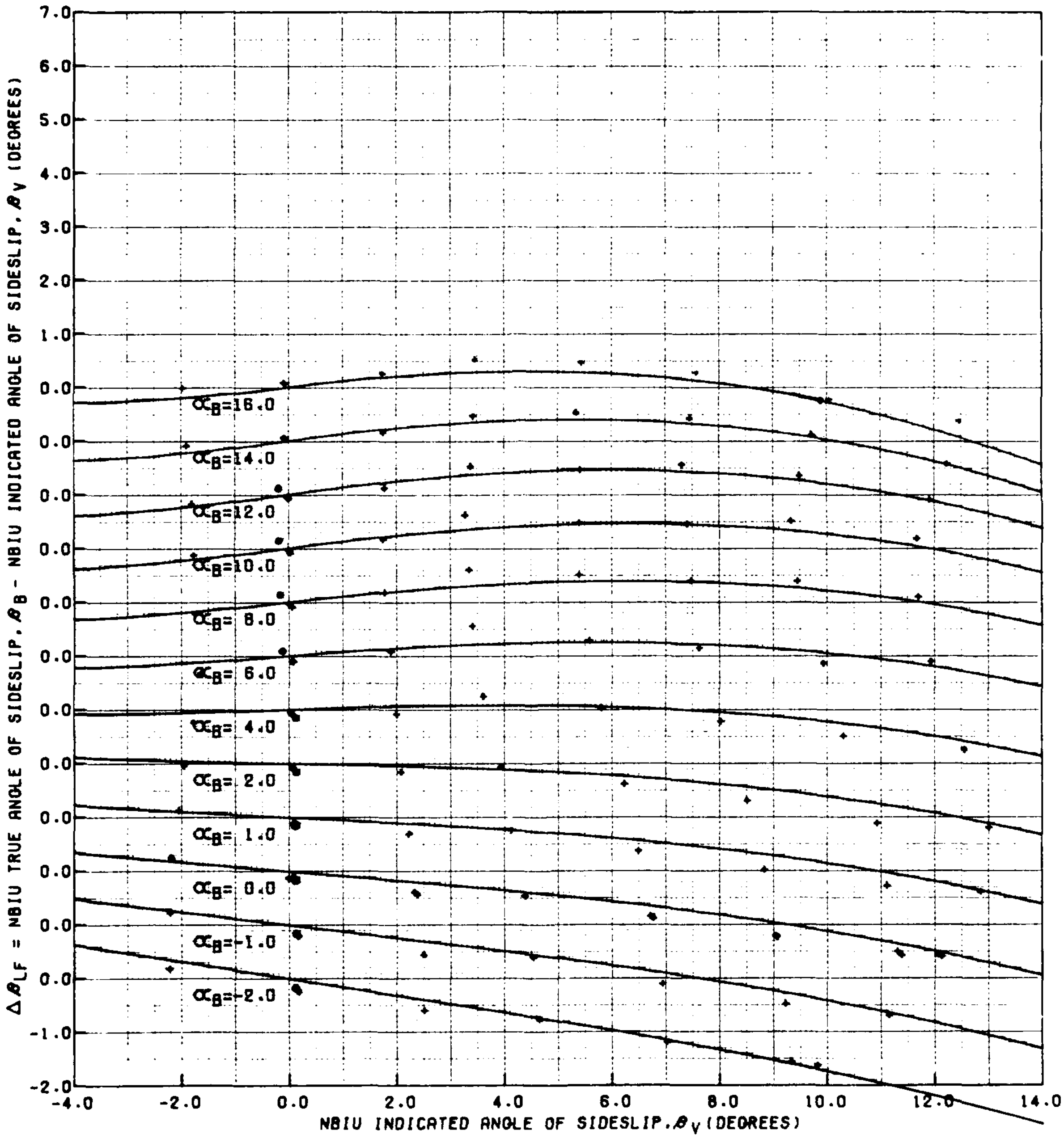


J) REFERENCE MACH NUMBER = 1.40
FIGURE B1: ANGLE OF SIDESLIP ERROR DUE TO LOCAL FLOW (CONTINUED)

AFFTC NBIU CALIBRATION
NASA/ARC 9- X 7-FOOT TUNNEL
TEST 11/97-731 - 1 MAY 1973

NOTES:
1. ACTUAL MACH NUMBER IS 1.55.
2. DATA REQUIRED NO CORRECTION FOR BIAS.

SYMBOL	EXPLANATION
⊙	$R_E/L = 2.0 \times 10^6$ (/FOOT)
+	$R_E/L = 4.0 \times 10^6$ (/FOOT)
——	AFFTC CURVE

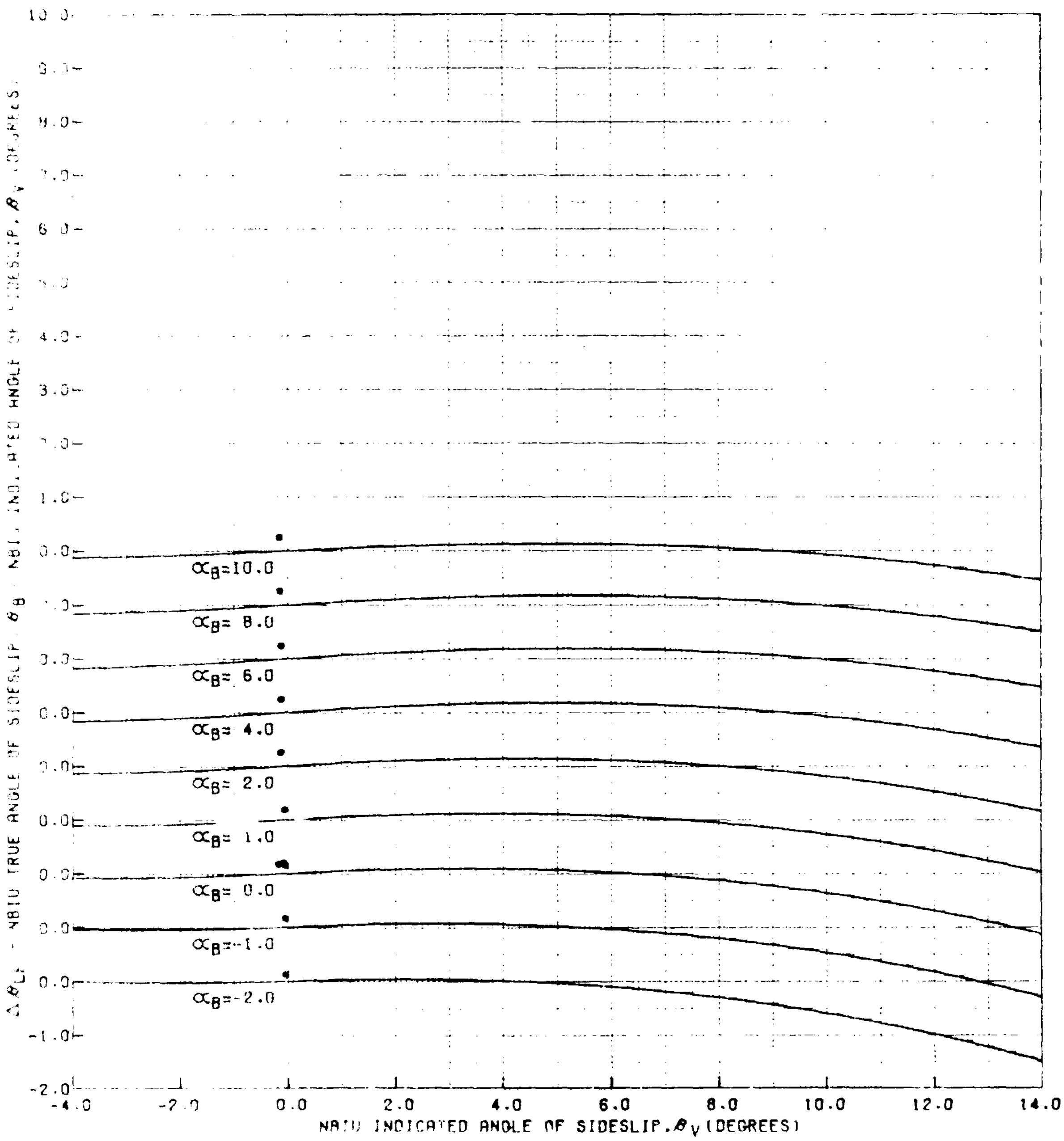


K) REFERENCE MACH NUMBER = 1.51
FIGURE B1: ANGLE OF SIDESLIP ERROR DUE TO LOCAL FLOW (CONTINUED)

AFFTC NBIU CALIBRATION
NASA/ARC 9- X 7 FOOT TUNNEL
TEST 11/97-731 - 1 MAY 1973

NOTES:
1. ACTUAL MACH NUMBER IS 1.72.
2. DATA REQUIRED NO CORRECTION FOR BIAS.

SYMBOL	EXPLANATION
⊙	$R_E/L = 3.7X10^6$(/FOOT)
---	AFFTC CURVE



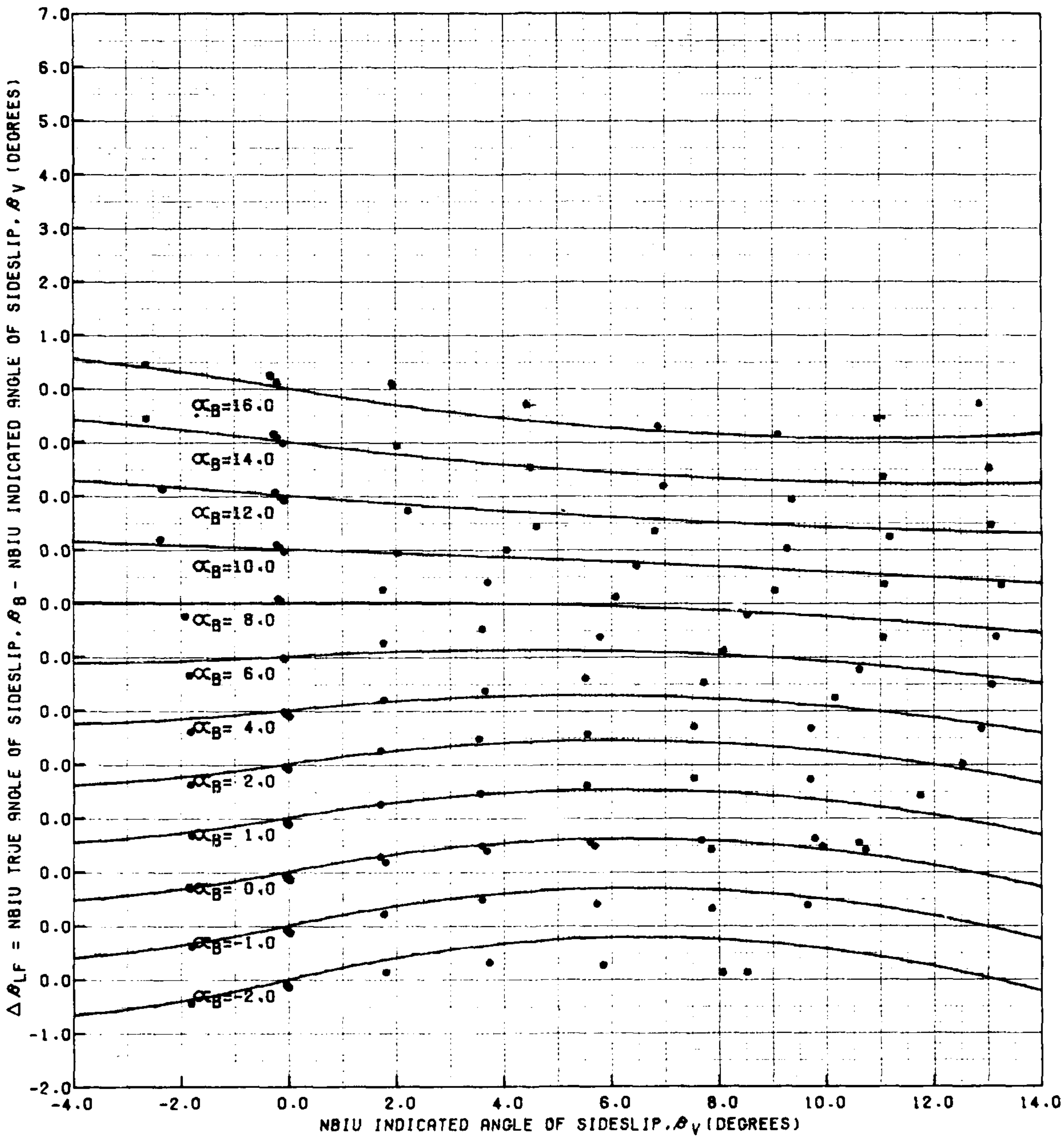
( ) REFERENCE MACH NUMBER = 1.71
FIGURE B1: ANGLE OF SIDESLIP ERROR DUE TO LOCAL FLOW (CONTINUED)

AFFTC NBIU CALIBRATION

NASA/ARC 9- X 7-FOOT TUNNEL
TEST 11/97-731 - 1 MAY 1973

NOTES:
1. ACTUAL MACH NUMBER IS 1.88.
2. DATA REQUIRED NO CORRECTION FOR BIAS.

SYMBOL	EXPLANATION
ʘ	$R_E/L = 4.3\times10^6$(/FOOT)
——	AFFTC CURVE



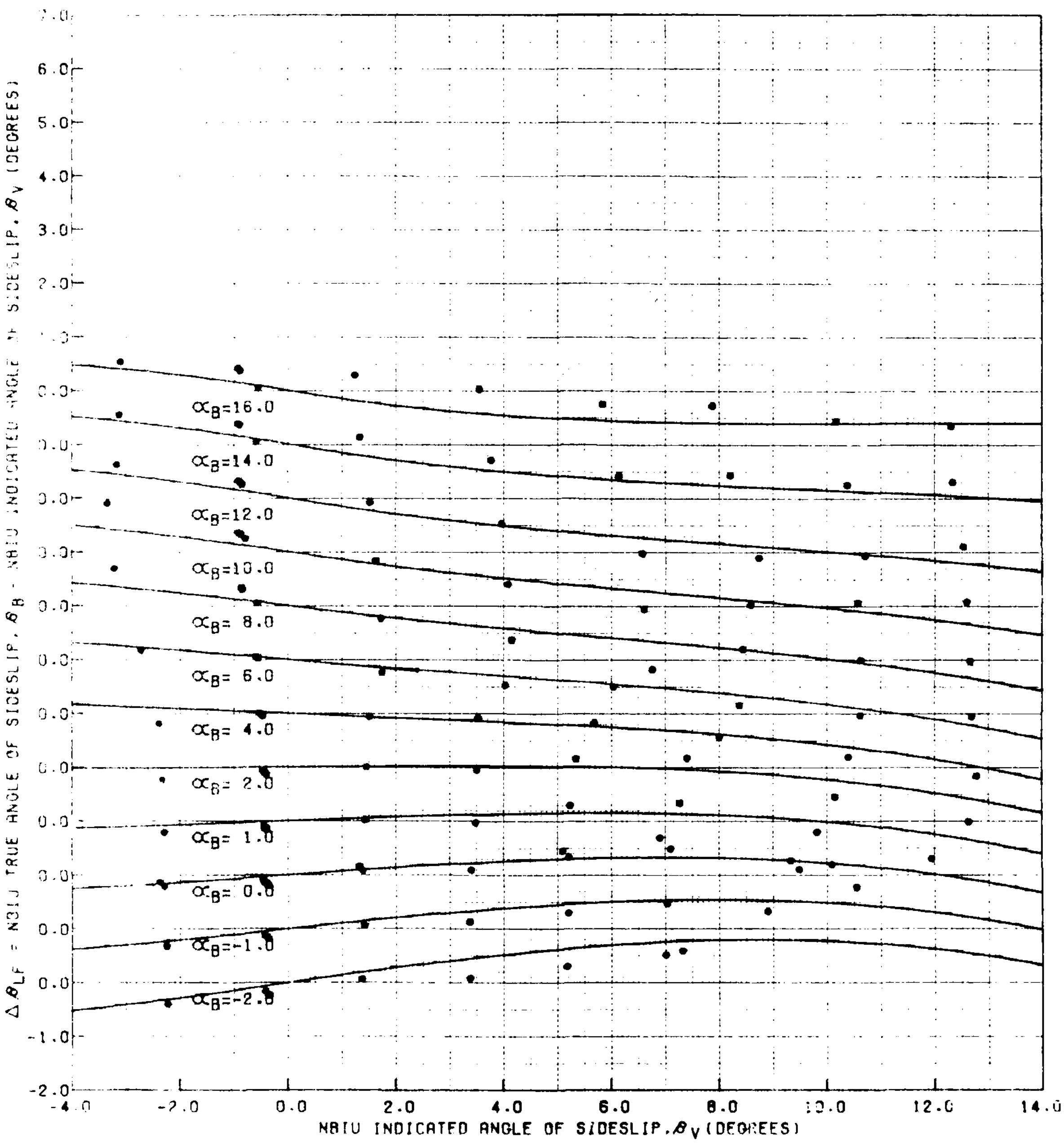
M) REFERENCE MACH NUMBER = 1.91

FIGURE B1: ANGLE OF SIDESLIP ERROR DUE TO LOCAL FLOW (CONTINUED)

AFFTC NBIU CALIBRATION
NASA/ARC 9- X 7-FOOT TUNNEL
TEST 11/97-731 - 1 MAY 1973

NOTES:
1. ACTUAL MACH NUMBER IS 2.07.
2. DATA REQUIRED NO CORRECTION FOR BIAS.

SYMBOL	EXPLANATION
⊙	$R_E/L = 4.2X10^6$(/FOOT)
——	AFFTC CURVE

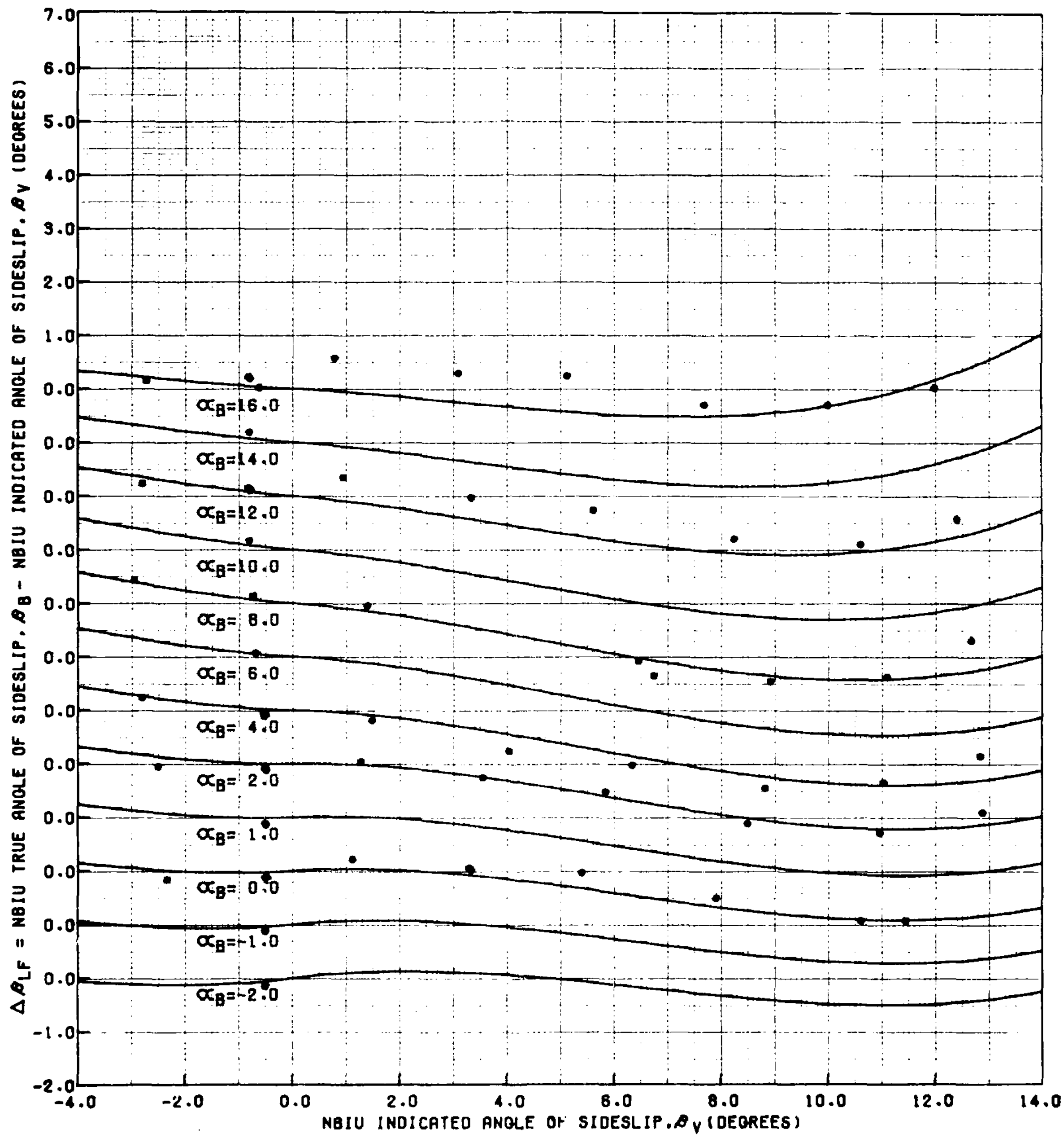


N) REFERENCE MACH NUMBER = 2.11
FIGURE B1: ANGLE OF SIDESLIP ERROR DUE TO LOCAL FLOW (CONTINUED)

AFFTC NBIU CALIBRATION
NASA/ARC 9- X 7-FOOT TUNNEL
TEST 11/97-731 - 1 MAY 1973

SYMBOL	EXPLANATION
⊙	$R_E/L = 4.1X10^6$(/FOOT)
——	AFFTC CURVE

NOTES:
1. ACTUAL MACH NUMBER IS 2.27.
2. DATA REQUIRED NO CORRECTION FOR BIAS.

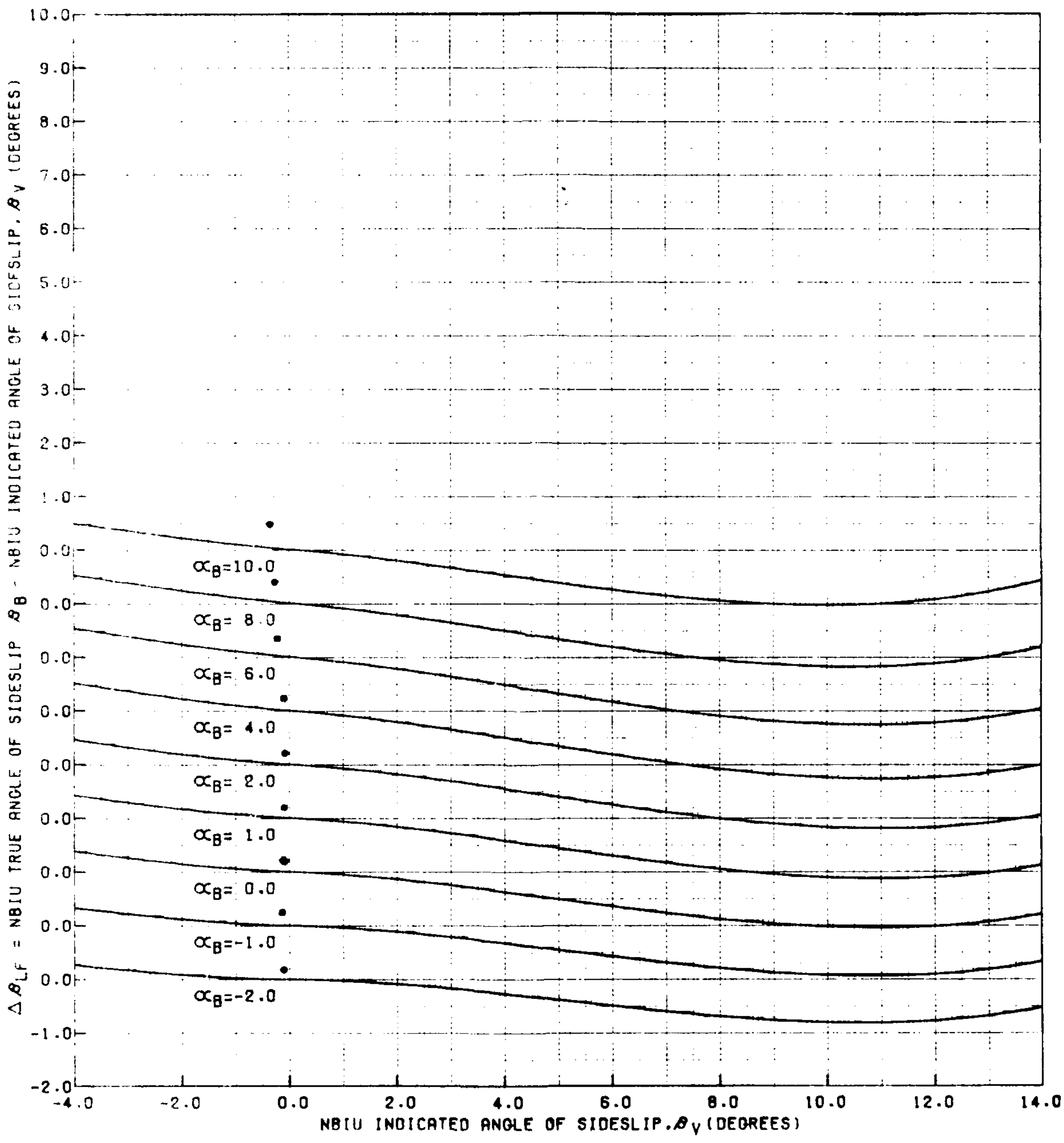


O) REFERENCE MACH NUMBER = 2.31
FIGURE B1: ANGLE OF SIDESLIP ERROR DUE TO LOCAL FLOW (CONTINUED)

AFFTC NBIU CALIBRATION
NASA/ARC 9- X 7-FOOT TUNNEL
TEST 11/97-731 - 1 MAY 1973

SYMBOL	EXPLANATION
O	$R_E/L = 3.7 \times 10^6$ (/FOOT)
——	AFFTC CURVE

NOTES:
1. ACTUAL MACH NUMBER IS 2.39.
2. DATA REQUIRED NO CORRECTION FOR BIAS.



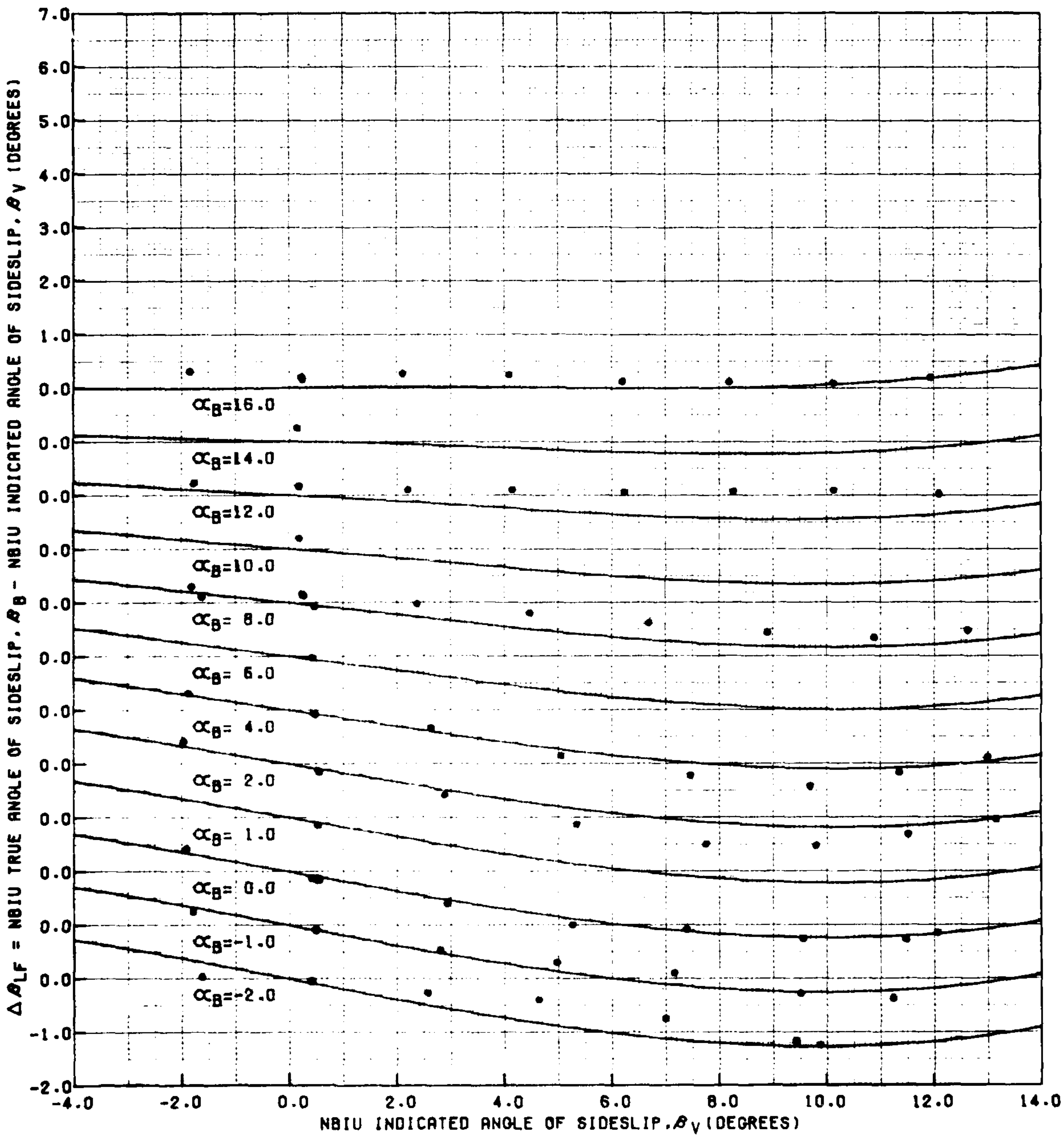
P) REFERENCE MACH NUMBER = 2.41

FIGURE 81: ANGLE OF SIDESLIP ERROR DUE TO LOCAL FLOW (CONTINUED)

AFFTC NBIU CALIBRATION
NASA/ARC 9- X 7-FOOT TUNNEL
TEST 11/97-731 - 1 MAY 1973

NOTES:
1. ACTUAL MACH NUMBER IS 2.55.
2. DATA REQUIRED NO CORRECTION FOR BIAS.

SYMBOL	EXPLANATION
⊙	R_E/L = 3.6X10[6] (/FOOT)
——	AFFTC CURVE



Q) REFERENCE MACH NUMBER = 2.54

FIGURE B1: ANGLE OF SIDESLIP ERROR DUE TO LOCAL FLOW (CONCLUDED)

APPENDIX C

PROGRAMMER'S GUIDE TO THE AFFTC NBIU CALIBRATION SOFTWARE

INTRODUCTION

Programmer information for the software which was developed to implement the fairings of the wind-tunnel calibration of the AFFTC NBIU is contained in this appendix. The software is not "stand alone" software, but was designed to be included in data reduction routines. These subroutines represent an "instrument calibration" for the NBIU which should be applied to the indicated values prior to corrections for pitch rate, upwash, or boom bending.

NBIU CALIBRATION SUBROUTINES

SUBROUTINE ANGLES:

Purpose. Subroutine ANGLES is the user interface with the NBIU calibration software. It is called with the indicated angle of attack, indicated angle of sideslip, freestream Mach number, and user-defined convergence factors (if desired) and returns NBIU true angle of attack, NBIU true angle of sideslip, and an error flag. It checks the input data and performs the outermost iteration involving convergence of angle of attack and angle of sideslip to their true values.

Conditions of Validity.

(1) The external configuration of the test NBIU must closely match the wind-tunnel configuration as described in the Test NBIU section of this memorandum.

(2) This subroutine requires the NBIU indicated angle of attack to be greater than -10.0 degrees and less than +40.0 degrees. If the value is outside these limits, no calculations are made and the NBIU true angle of attack returned is the same as the value when ANGLES was called whether from user initialization, a previous call, or computer core initialization.

(3) This subroutine requires the NBIU indicated angle of sideslip to be greater than -15.0 degrees and less than +15.0 degrees. If the value is outside these limits, no calculations are made and the NBIU true angle of sideslip returned is the same as the value when ANGLES was called whether from user initialization, a previous call, or computer core initialization.

(4) It is assumed that Mach number input will be greater than 0.0 and will not exceed 2.55 by a significant amount. No checks are made within the NBIU calibration software on Mach number. Values less than 0.0 obviously represent invalid data which the user must edit. Values greater than 2.55 cause extrapolation of curves which were defined by data less than or equal to 2.55. The extrapolated values may or may not be valid and confidence decreases rapidly as Mach number increases.

(5) It is assumed that the user will either accept the default values of convergence factor (the allowable difference between two consecutive iterations) on angle of attack and angle of sideslip, or substitute reasonable values. Increasing or decreasing the convergence factors may decrease or increase run time by a very small amount. Any decrease or small increase in the convergence factors will not significantly affect accuracy, but large increases could reduce the accuracy significantly.

Storage Required.

	OCTAL WORDS	DECIMAL WORDS
	156	110

Subprograms Used.

DELALF, DELBET, ABS(absolute function)

Calling Statement.

CALL ANGLES(ALFAV,BETAV,AMCT,CONVRA,CONVRB,ALPHA,BETA,IFLAG)

Calling Argument Input.

INPUT		DESCRIPTION	UNITS
α_v	ALFAV	NBIU indicated angle of attack	deg
β_v	BETAV	NBIU indicated angle of sideslip	deg
M	AMCT	freestream Mach number	N-D
$\Delta\alpha_{con}$	CONVRA	angle-of-attack convergence factor	deg
$\Delta\beta_{con}$	CONVRB	angle-of-sideslip convergence factor	deg

Calling Argument Output.

OUTPUT		DESCRIPTION	UNITS
α	ALPHA	NBIU true angle of attack	deg
β	BETA	NBIU true angle of sideslip	deg
	IFLAG	error flag (see Error Flag Structure subsection)	---

Major Internal Variables.

VARIABLE		DESCRIPTION	UNITS
α'	ALFAP	previous iteration value of ALPHA	deg
β'	BETAP	previous iteration value of BETA	deg
$\lvert\Delta\alpha\rvert$	DALFA	absolute value of difference in ALPHA between two consecutive iterations	deg
$\lvert\Delta\beta\rvert$	DBETA	absolute value of difference in BETA between two consecutive iterations	deg

Error Flag Structure.

The error flag output by ANGLES denotes an error and/or errors which occurred within the NBIU calibration software. The flag value can be decoded to define all critical errors which occur with the possible exception of problems caused by user input of Mach number or convergence factors. The error flag uses two digits to define errors or error combinations; the 1's digit denotes an error in the input data or problems with convergence of either angle of attack or angle of sideslip and the 10's digit denotes problems with convergence of the larger iteration involving both angle of attack and angle of sideslip. The errors are summarized below where an X in either the 1's or 10's digit denotes insignificance of the digit value to the particular error. It should be noted that any but the first or second value of the error flag denotes software problems rather than data problems. Convergence failure with the default convergence factors indicates a problem at the intersection of two segments of the curves which was undetected during checkout or, more likely, a card which was inadvertently changed during copying or loading of the routines. Although no convergence failure has ever been noted with the final software, the user should provide appropriate checks of the error flag to insure that valid results are being obtained.

IFLAG VALUE	DESCRIPTION OF ERRORS
0	No errors encountered
1	Input value of ALFAV or BETAV is outside allowable limits: No calculations are made; ALFA and BETA values returned or from previous calls or user initialized values
X2	Convergence within subroutine CNVRG on angle of attack failed to converge within 20 iterations
X3	Convergence within subroutine CNVRG on angle of sideslip failed to converge within 20 iterations
X5	Convergence within subroutine CNVRG on both angle of attack and angle of sideslip failed to converge within 20 iterations
2X	Convergence within subroutine ANGLES on angle of attack failed to converge within 20 iterations
3X	Convergence within subroutine ANGLES on angle of sideslip failed to converge within 20 iterations
5X	Convergence within subroutine ANGLES on both angle of attack and angle of sideslip failed to converge within 20 iterations

Program Description. Subroutine ANGLES receives inputs from user routines, sets the convergence factors to the default values if none are specified, and checks that input values are within acceptable limits. If all inputs are within limits, it initializes the "true" angles of attack and sideslip to the indicated values. Based on the best estimates of the true angles, errors due to local flow are calculated and the estimates of true angles are updated. The process of calculating errors due to local flow and updating the estimates of the true angles continues until both alpha and beta on two consecutive iterations are within their respective convergence factors. If either iteration fails to converge after 20 passes, the error flag is set and the value of ALPHA and BETA returned is the last estimate. The flow diagram and program listing which follow provide details of the subroutine operation.

Program Listing.

```
      SUBROUTINE ANGLES(ALFAV,BETAV,AMCT,CONVRA,CONVRB,ALPHA,BETA,IFLAG)
C     ******************************************************************
C
C     SUBROUTINE ANGLES DETERMINES TRUE ANGLE OF ATTACK AND TRUE ANGLE
C     OF SIDESLIP GIVEN THE INDICATED VALUES FOR THE STANDARD AFFTC
C     NOSEBOOM INSTRUMENTATION UNIT (NBIU) AS REFERENCED IN REPORT
C     AFFTC-TIM-81-2,"AERODYNAMIC CHARACTERISTICS OF THE AFFTC NOSEBOOM
C     INSTRUMENTATION UNIT". LIMITS FOR INDICATED ANGLE OF ATTACK ARE
C     -10.0 TO +40.0 DEGREES AND FOR INDICATED ANGLE OF SIDESLIP ARE
C     -15.0 TO +15.0 DEGREES.
C
C     EXTERNAL VARIABLES-
C              NAME      DESCRIPTION                             UNITS
C     INPUT  - ALFAV   - BOOM INDICATED ANGLE OF ATTACK        - DEGREES
C              BETAV   - BOOM INDICATED ANGLE OF SIDESLIP      - DEGREES
C              AMCT    - FREESTREAM MACH NUMBER                - *******
C              CONVRA  - ITERATION CONVERGENCE FACTOR FOR
C                        ANGLE OF ATTACK (DEFAULT=.000001)     - DEGREES
C              CONVRB  - ITERATION CONVERGENCE FACTOR FOR
C                        ANGLE OF SIDESLIP (DEFAULT=.000001) - DEGREES
C     OUTPUT - ALPHA   - BOOM TRUE ANGLE OF ATTACK             - DEGREES
C              BETA    - BOOM TRUE ANGLE OF SIDESLIP           - DEGREES
C              IFLAG   - ERROR FLAG                            - *******
C                        IFLAG= 0,NO ERRORS ENCOUNTERED
C                        IFLAG= 1,ALFAV OR BETAV IS OUTSIDE
C                                 ALLOWABLE LIMITS
C                        IFLAG=X2,CNVRG INTERNAL CONVERGENCE
C                                 ON ANGLE OF ATTACK FAILED
C                        IFLAG=X3,CNVRG INTERNAL CONVERGENCE
C                                 ON ANGLE OF SIDESLIP FAILED
C                        IFLAG=X5,CNVRG INTERNAL CONVERGENCE
C                                 ON ANGLE OF ATTACK AND
C                                 ON ANGLE OF SIDESLIP FAILED
C                        IFLAG=2X,ALFA CONVERGENCE INCOMPLETE
C                                 AFTER 20 ITERATIONS
C                        IFLAG=3X,BETA CONVERGENCE INCOMPLETE
C                                 AFTER 20 ITERATIONS
C                        IFLAG=5X,ALFA AND BETA CONVERGENCE
C                                 INCOMPLETE AFTER 20
C                                 ITERATIONS
C
```

```
C     REVISION RECORD-                                                  ANGLES42
C                NAME                              DATE                 ANGLES43
C     WRITTEN BY - MARK KORSMO                      9 FEB 1978          ANGLES44
C     REVISED BY - KEN RAWLINGS                    23 JUL 1981          ANGLES45
C                                                                       ANGLES46
C     ******************************************************************ANGLES47
      DATA CONA,CONB/.000001,.000001/                                   ANGLES48
C     SET DEFAULT VALUES FOR CONVERGENCE FACTORS -----------------------ANGLES49
      IF(CONVRA .EQ. 0.0) CONVRA=CONA                                   ANGLES50
      IF(CONVRB .EQ. 0.0) CONVRB=CONB                                   ANGLES51
C     CHECK FOR INPUT VALUES OUTSIDE LIMITS ----------------------------ANGLES52
      IFLAG=1                                                           ANGLES53
      IF((ALFAV .LT. -10.0) .OR. (ALFAV .GT. 40.0)) RETURN              ANGLES54
      IF((BETAV .LT. -15.0) .OR. (BETAV .GT. 15.0)) RETURN              ANGLES55
C     INITIALIZE ITERATION VARIABLES -----------------------------------ANGLES56
      IFLAG=0                                                           ANGLES57
      ALPHA=ALFAV                                                       ANGLES58
      BETA =BETAV                                                       ANGLES59
C     ITERATE TO OBTAIN ALPHA AND BETA ---------------------------------ANGLES60
      DO 100 I=1,20                                                     ANGLES61
      ALFAP=ALPHA                                                       ANGLES62
      BETAP=BETA                                                        ANGLES63
      CALL DELALF(ALFAV,BETA ,AMCT,CONVRA,IFLAG,ALPHA)                  ANGLES64
      CALL DELBET(ALPHA,BETAV,AMCT,CONVRB,IFLAG,BETA )                  ANGLES65
      DALFA=ABS(ALPHA-ALFAP)                                            ANGLES66
      DBETA=ABS(BETA -BETAP)                                            ANGLES67
      IF((DALFA .LE. CONVRA) .AND. (DBETA .LE.CONVRB)) RETURN           ANGLES68
  100 CONTINUE                                                          ANGLES69
C     SET FLAG DENOTING FAILURE OF ALPHA/BETA ITERATION TO CONVERGE ----ANGLES70
      IF(DALFA  .GT. CONVRA) IFLAG=IFLAG+20                             ANGLES71
      IF(DBETA  .GT. CONVRB) IFLAG=IFLAG+30                             ANGLES72
      RETURN                                                            ANGLES73
      END                                                               ANGLES74
```

SUBROUTINE DELALF:

Purpose. Subroutine DELALF calculates the NBIU true angle of attack from the NBIU indicated angle of attack, NBIU true angle of sideslip and freestream Mach number. DELALF is called from the iterative loop in subroutine ANGLES with the NBIU true angle of sideslip equal to the latest estimate in order to update the estimate of NBIU true angle of attack.

Storage Required.

OCTAL WORDS	DECIMAL WORDS
55	45

Subprograms Used.

DALFA0, COS (cosine function), ABS (absolute function)

Calling Statement.

CALL DELALF (ALFAV,BETA,AMCT,CONVRA,IFLAG,ALPHA)

Calling Argument Input.

INPUT		DESCRIPTION	UNITS
α_v	ALFAV	NBIU indicated angle of attack	deg
β	BETA	NBIU true angle of sideslip	deg
M	AMCT	freestream Mach number	N-D
$\Delta\alpha_{con}$	CONVRA	angle-of-attack convergence factor	deg
	IFLAG	error flag (see Error Flag Structure, Subroutine ANGLES)	---

Calling Arguments Output.

OUTPUT		DESCRIPTION	UNITS
α	ALPHA	NBIU true angle of attack	deg
	IFLAG	error flag (see Error Flag Structure, Subroutine ANGLES)	---

Major Internal Variables.

VARIABLE		DESCRIPTION	UNITS
α_0	ALPHA0	NBIU true angle of attack for input indicated angle of attack and freestream Mach number but NBIU true angle of sideslip equal 0.0	deg
$\Delta\alpha_\beta$	DALFBT	change in NBIU true angle of attack due to NBIU true angle of sideslip	deg

Program Description. Subroutine DELALF calculates the NBIU true angle of attack in two steps. First, subroutine DALFA0 is called to calculate the true angle of attack for the input indicated angle of attack and Mach number, variable ALPHA0. For Mach numbers less than 1.0, a small correction for angle of sideslip, variable DALFBT, is calculated and added to variable ALPHA0 to obtain the NBIU true angle of attack.

Program Listing.

```
      SUBROUTINE DELALF(ALFAV,BETA,AMCT,CONVRA,IFLAG,ALPHA)
C     ******************************************************************
C
C     SUBROUTINE DELALF DETERMINES BOOM TRUE ANGLE OF ATTACK GIVEN THE
C     BOOM INDICATED ANGLE OF ATTACK AND TRUE ANGLE OF SIDESLIP. THE
C     TRUE ANGLE OF ATTACK IS CALCULATED FOR 0.0 DEGREES ANGLE OF
C     SIDESLIP AND A SMALL DELTA IS ADDED TO ACCOUNT FOR ANGLE OF
C     SIDESLIP EFFECTS.
C
C     EXTERNAL VARIABLES-
C              NAME      DESCRIPTION                              UNITS
C     INPUT  - ALFAV   - BOOM INDICATED ANGLE OF ATTACK         - DEGREES
C              BETA    - BOOM TRUE ANGLE OF SIDESLIP            - DEGREES
C              AMCT    - FREESTREAM MACH NUMBER                 - *******
C              CONVRA  - ITERATION CONVERGENCE FACTOR FOR
C                        ANGLE OF ATTACK                        - DEGREES
C              IFLAG   - ERROR FLAG                             - *******
C     OUTPUT - ALPHA   - BOOM TRUE ANGLE OF ATTACK              - DEGREES
C              CONVRA  - ITERATION CONVERGENCE FACTOR FOR
C                        ANGLE OF ATTACK                        - DEGREES
C              IFLAG   - ERROR FLAG                             - *******
C
C     REVISION RECORD-
C                  NAME                          DATE
C     WRITTEN BY - MARK KORSMO                    9 FEB 1978
C     REVISED BY - KEN RAWLINGS                  23 JUL 1981
C
C     ******************************************************************
      REAL INTR
C     CALCULATE TRUE ANGLE OF ATTACK AT 0.0 DEGREES ANGLE OF SIDESLIP --
      CALL DALFA0(ALFAV,AMCT,CONVRA,IFLAG,ALPHA0)
C     CALCULATE CHANGE IN ANGLE OF ATTACK DUE TO ANGLE OF SIDESLIP -----
      DALFBT=0.0
      IF(AMCT .GT. 1.00) GO TO 100
      SLOP=+15.0*(1.-COS(ABS(BETA)/57.296))
      INTR=-15.0*(1.-COS(ABS(BETA)/57.296))
      DALFBT=INTR+(SLOP*AMCT*AMCT)
  100 ALPHA=ALPHA0+DALFBT
      RETURN
      END
```

SUBROUTINE DALFAO:

Purpose. Subroutine DALFA0 calculates the value the NBIU true angle would have for the NBIU indicated angle of attack and freestream Mach number (using data fairings for) 0.0 degrees angle of sideslip.

Storage Required.

OCTAL WORDS	DECIMAL WORDS
340	224

Subprograms Used.

CNVRG, ABS (absolute function)

Calling Statement.

CALL DALFA0(ALFAV,AMCT,CONVRA,IFLAG,ALPHA0)

Calling Argument Input.

INPUT		DESCRIPTION	UNITS
α_V	ALFAV	NBIU indicated angle of attack	deg
M	AMCT	freestream Mach number	N-D
$\Delta\alpha_{con}$	CONVRA	angle-of-attack convergence factor	deg
	IFLAG	error flag (see Error Flag Structure, Subroutine ANGLES)	---

Calling Argument Output.

OUTPUT		DESCRIPTION	UNITS
	IFLAG	error flag (see Error Flag Structure, Subroutine ANGLES)	---
α_0	ALPHA0	NBIU true angle of attack for the input values at 0.0 degrees angle of sideslip	deg

Program Description. Subroutine DALFA0 calculates the NBIU true angle of attack for the NBIU indicated angle and freestream Mach number using data fairings for 0.0 degrees angle of sideslip. The fairings were done in five segments covering various Mach number ranges. All fairings were done in terms of local flow error versus true angle of attack and Mach number so subroutine CNVRG was called to iterate to obtain true angle of attack from the indicated value.

AD-A118 315 AIR FORCE FLIGHT TEST CENTER EDWARDS AFB CA F/G 1/3
AERODYNAMIC CHARACTERISTICS OF THE AFFTC NOSEBOOM INSTRUMENTATI--ETC(U)
MAR 82 K RAWLINGS, M T KORSMO
UNCLASSIFIED AFFTC-TIM-81-2-VOL-1 NL

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Program Listing.

```
      SUBROUTINE DALFAO(ALFAV,AMCT,CONVRA,IFLAG,ALPHAO)
C*********************************************************************
C
C     SUBROUTINE DALFAO DETERMINES BOOM TRUE ANGLE OF ATTACK GIVEN THE
C     BOOM INDICATED ANGLE OF ATTACK AND CORRESPONDING FREESTREAM MACH
C     NUMBER. THE SUBROUTINE IS VALID ONLY AT 0.0 DEGREES ANGLE OF
C     SIDESLIP.
C
C     EXTERNAL VARIABLES-
C               NAME      DESCRIPTION                          UNITS
C     INPUT  - ALFAV   - BOOM INDICATED ANGLE OF ATTACK      - DEGREES
C              AMCT    - FREESTREAM MACH NUMBER              - *******
C              CONVRA  - ITERATION CONVERGENCE FACTOR FOR
C                        ANGLE OF ATTACK                     - DEGREES
C              IFLAG   - ERROR FLAG                          - *******
C     OUTPUT - ALPHAO  - BOOM TRUE ANGLE OF ATTACK AT 0.0
C                        DEGREES ANGLE OF SIDESLIP           - DEGREES
C              IFLG    - ITERATION REQUEST FLAG              - *******
C                        IFLG=2,ITERATION REQUESTED ON ANGLE
C                               OF ATTACK
C              IFLAG   - ERROR FLAG                          - *******
C
C     REVISION RECORD-
C                   NAME                          DATE
C     WRITTEN BY - MARK KORSMO                     9 FEB 1978
C     REVISED BY - KEN RAWLINGS                    8 JAN 1982
C
C*********************************************************************
      DATA IFLG/2/
C     SET VALUES OF CONSTANTS FROM CURVE FITS -------------------------
      DATA B11,B21,S11,S21/ -1.18395, -0.70130, -0.42941, +0.00111/
      DATA B12,B22,S12,S22/ +0.00000, +0.00000, -1.45250, -1.31721/
      DATA B13,B23,S13,S23/ -0.33865, -7.31612, -0.56863, +2.95072/
      DATA B14,B24,S14,S24/ -2.72322, -0.14655, +0.47719, -0.19369/
C     DETERMINE TRUE ANGLE OF ATTACK AT 0.0 DEGREES ANGLE OF SIDESLIP --
      IF(AMCT  .LE.  1.000) GO TO 100
      IF(AMCT  .LE.  1.100) GO TO 200
      IF(AMCT  .LE.  1.300) GO TO 300
      IF(AMCT  .LT.  1.510) GO TO 600
      GO TO 700
```

```
C     ALPHAO FOR MACH NUMBER LESS THAN 1.000--------------------------DALFA041
  100 CALL CNVRG(B11,B21,S11,S21,ALFAV,AMCT,CONVRA,IFLG,ALPHAO,IFLAG)   DALFA042
      ALPHAO=ALPHAO+(0.2935*(1.0-AMCT)**2)                              DALFA043
      RETURN                                                            DALFA044
C     ALPHAO FOR MACH NUMBER BETWEEN 1.000 AND 1.100-------------------DALFA045
  200 AMC1=1.00                                                         DALFA046
      AMC2=1.10                                                         DALFA047
      CALL CNVRG(B11,B21,S11,S21,ALFAV,AMC1,CONVRA,IFLG,ALFA1,IFLAG)    DALFA048
      CALL CNVRG(B12,B22,S12,S22,ALFAV,AMC2,CONVRA,IFLG,ALFA2,IFLAG)    DALFA049
      FACTOR=((AMCT*AMCT)-(AMC1*AMC1))  /  ((AMC2*AMC2)-(AMC1*AMC1))    DALFA050
      ALPHAO=ALFA1+(FACTOR*(ALFA2-ALFA1))                               DALFA051
      RETURN                                                            DALFA052
C     ALPHAO FOR MACH NUMBER BETWEEN 1.10 AND 1.30---------------------DALFA053
  300 AMC1=1.10                                                         DALFA054
      AMC2=1.30                                                         DALFA055
      CALL CNVRG(B12,B22,S12,S22,ALFAV,AMC1,CONVRA,IFLG,ALFA1,IFLAG)    DALFA056
      IF(ABS(ALFAV).LE.(10.94851+((-0.14060)*(AMCT*AMCT))))GO TO 400    DALFA057
      CALL CNVRG(B13,B23,S13,S23,ALFAV,AMC2,CONVRA,IFLG,ALFA2,IFLAG)    DALFA058
      GO TO 500                                                         DALFA059
  400 CALL CNVRG(B14,B24,S14,S24,ALFAV,AMC2,CONVRA,IFLG,ALFA2,IFLAG)    DALFA060
  500 FACTOR=((AMCT*AMCT)-(AMC1*AMC1))  /  ((AMC2*AMC2)-(AMC1*AMC1))    DALFA061
      ALPHAO=ALFA1+(FACTOR*(ALFA2-ALFA1))                               DALFA062
      RETURN                                                            DALFA063
C     ALPHAO FOR MACH NUMBER BETWEEN 1.30 AND 1.51---------------------DALFA064
  600 IF(ABS(ALFAV).LE.(10.94851+((-0.14060)*(AMCT*AMCT))))GO TO 700    DALFA065
      CALL CNVRG(B13,B23,S13,S23,ALFAV,AMCT,CONVRA,IFLG,ALPHAO,IFLAG)   DALFA066
      RETURN                                                            DALFA067
C     ALPHAO FOR MACH NUMBER GREATER THAN 1.51-------------------------DALFA068
  700 CALL CNVRG(B14,B24,S14,S24,ALFAV,AMCT,CONVRA,IFLG,ALPHAO,IFLAG)   DALFA069
      RETURN                                                            DALFA070
      END                                                               DALFA071
```

SUBROUTINE DELBET:

Purpose: Subroutine DELBET calculates the NBIU true angle of sideslip from the NBIU indicated angle of sideslip, NBIU true angle of attack and freestream Mach number. DELBET is called from the iterative loop in subroutine ANGLES with the NBIU true angle of attack equal to the latest estimate in order to update the estimate of NBIU true angle of sideslip.

Storage Required.

OCTAL WORDS	DECIMAL WORDS
345	229

Subprograms Used.

COS (cosine function), DBETA0, ABS (absolute function)

Calling Statement.

CALL DELBET (ALPHA,BETAV,AMCT,CONVRB,IFLAG,BETA)

Calling Argument Input.

INPUT		DESCRIPTION	UNITS
α	ALPHA	NBIU true angle of attack	deg
β_V	BETAV	NBIU indicated angle of sideslip	deg
M	AMCT	freestream Mach number	N-D
$\Delta\beta_{con}$	CONVRB	angle-of-sideslip convergence factor	deg
	IFLAG	error flag (see Error Flag Structure, Subroutine ANGLES)	---

Calling Argument Output.

OUTPUT		DESCRIPTION	UNITS
β	BETA	NBIU true angle of sideslip	deg
	IFLAG	error flag (see Error Flag Structure, Subroutine ANGLES)	---

Major Internal Variables.

VARIABLE		DESCRIPTION	UNITS
β_0	BETA0	NBIU true angle of sideslip for input indicated angle of sideslip and freestream Mach number but NBIU true angle of attack equal 0.0	deg
$\Delta\beta_\alpha$	DB	change in NBIU true angle of sideslip due to angle of attack (subscripts of 1 or 2 are used to denote Mach number)	deg

Program Description. Subroutine DELBET calculates the NBIU true angle of sideslip in two steps. First, subroutine DBETA0 is called to calculate the true angle of sideslip for the input indicated angle of sideslip and Mach number, variable BETA0. A correction for angle of attack is then calculated and added to variable BETA0 to obtain the NBIU true angle of sideslip.

Program Listing.

```
      SUBROUTINE DELBET(ALPHA,BETAV,AMCT,CONVRB,IFLAG,BETA)
C***********************************************************************
C
C     SUBROUTINE DELBET DETERMINES BOOM TRUE ANGLE OF SIDESLIP GIVEN THE
C     BOOM INDICATED ANGLE OF SIDESLIP AND TRUE ANGLE OF ATTACK. THE
C     TRUE ANGLE OF SIDESLIP IS CALCULATED FOR 0.0 DEGREES ANGLE OF
C     ATTACK AND A SMALL DELTA IS ADDED TO ACCOUNT FOR ANGLE OF ATTACK
C     EFFECTS.
C
C     EXTERNAL VARIABLES-
C              NAME       DESCRIPTION                            UNITS
C     INPUT  - ALPHA    - BOOM TRUE ANGLE OF ATTACK            - DEGREES
C              BETAV    - BOOM INDICATED ANGLE OF SIDESLIP     - DEGREES
C              AMCT     - FREESTREAM MACH NUMBER               - *******
C              CONVRB   - ITERATION CONVERGENCE FACTOR FOR
C                         ANGLE OF SIDESLIP (DEFAULT=.000001) - DEGREES
C              IFLAG    - ERROR FLAG                           - *******
C     OUTPUT - BETA     - BOOM TRUE ANGLE OF SIDESLIP          - DEGREES
C              IFLAG    - ERROR FLAG                           - *******
C
C     REVISION RECORD-
C                  NAME                          DATE
C     WRITTEN BY - MARK KURSMO                    9 FEB 1978
C     REVISED BY - KEN RAWLINGS                   6 NOV 1981
C
C***********************************************************************
      REAL INT,INT18
      DIMENSION A(3),B(3),C(3),D(3),E(3)
C     SET VALUES OF CONSTANTS FROM CURVE FITS -------------------------
      DATA A                   /-.7793061E-3,+.3574667E-1,-.1413029E-2/
      DATA B                   /+.1443219E-2,-.2264961E-1,+.0000000E00/
      DATA C                   /+.9967097E-3,-.3501526E-1,+.1236146E-2/
      DATA D                   /+.1059054E-2,-.2787444E-1,+.1296875E-2/
      DATA E                   /-.4961146E-3,+.7073456E-2,+.3726786E-3/
C     DEFINE STATEMENT FUNCTION ---------------------------------------
      DBET(S,T,U,A,B)=(S*B*ABS(B)*A)+(T*B*A)+(U*B*A*A)
C     CALCULATE TRUE ANGLE OF SIDESLIP AT 0.0 DEGREES ANGLE OF ATTACK --
      CALL DBETA0(BETAV,AMCT,CONVRB,IFLAG,BETA0)
C     CALCULATE CHANGE IN ANGLE OF SIDESLIP DUE TO ANGLE OF ATTACK -----
      IF(AMCT .LE. 1.30) GO TO 100
      IF(AMCT .LE. 1.55) GO TO 200
      IF(AMCT .LE. 1.88) GO TO 300
      IF(AMCT .LE. 2.07) GO TO 400
      IF(AMCT .LE. 2.27) GO TO 500
      GO TO 600
```

```
C     BETA FOR MACH NUMBER LESS THAN 1.300 --------------------- ------DELBET46
  100 SLOP18=11.444444*(1.-(COS(BETAV/57.296))**2)                      DELBET47
      SLOPE=SLOP18+(SLOP18/.048943)*(1.-COS(ABS(ALPHA/57.296))-.048943) DELBET48
      INT18=-25.25*(1.-(COS(BETAV/57.296))**2)                          DELBET49
      INT=INT18+(INT18/(.048943))*((1.-COS(ABS(ALPHA/57.296)))-.048943) DELBET50
      DB1=INT+SLOPE*AMCT*AMCT                                           DELBET51
      IF(BETAV.LT.0.)DB1=-DB1                                           DELBET52
      BETA=BETA0+DB1                                                    DELBET53
      RETURN                                                            DELBET54
C     BETA FOR MACH NUMBER BETWEEN 1.300 AND 1.550 --------------------DELBET55
  200 AM1=1.30                                                          DELBET56
      AM2=1.55                                                          DELBET57
      SLOP18=11.444444*(1.-(COS(BETAV/57.296))**2)                      DELBET58
      SLOPE=SLOP18+(SLOP18/.048943)*(1.-COS(ABS(ALPHA/57.296))-.048943) DELBET59
      INT18=-25.25*(1.-(COS(BETAV/57.296))**2)                          DELBET60
      INT=INT18+(INT18/(.048943))*((1.-COS(ABS(ALPHA/57.296)))-.048943) DELBET61
      DB1=INT + SLOPE*AM1*AM1                                           DELBET62
      IF(BETAV.LT.0.)DB1=-DB1                                           DELBET63
      DB2=DBET(A(1),A(2),A(3),ALPHA,BETAV)                              DELBET64
      FACTOR=((AMCT*AMCT)-(AM1*AM1))/((AM2*AM2)-(AM1*AM1))              DELBET65
      BETA=BETA0+(DB1+(FACTOR*(DB2-DB1)))                               DELBET66
      RETURN                                                            DELBET67
C     BETA FOR MACH NUMBER BETWEEN 1.550 AND 1.880 --------------------DELBET68
  300 AM1=1.55                                                          DELBET69
      AM2=1.88                                                          DELBET70
      DB1=DBET(A(1),A(2),A(3),ALPHA,BETAV)                              DELBET71
      DB2=DBET(B(1),B(2),B(3),ALPHA,BETAV)                              DELBET72
      FACTOR=((AMCT*AMCT)-(AM1*AM1))/((AM2*AM2)-(AM1*AM1))              DELBET73
      BETA=BETA0+(DB1+(FACTOR*(DB2-DB1)))                               DELBET74
      RETURN                                                            DELBET75
C     BETA FOR MACH NUMBER BETWEEN 1.880 AND 2.070 --------------------DELBET76
  400 AM1=1.88                                                          DELBET77
      AM2=2.07                                                          DELBET78
      DB1=DBET(B(1),B(2),B(3),ALPHA,BETAV)                              DELBET79
      DB2=DBET(C(1),C(2),C(3),ALPHA,BETAV)                              DELBET80
      FACTOR=((AMCT*AMCT)-(AM1*AM1))/((AM2*AM2)-(AM1*AM1))              DELBET81
      BETA=BETA0+(DB1+(FACTOR*(DB2-DB1)))                               DELBET82
      RETURN                                                            DELBET83
C     BETA FOR MACH NUMBER BETWEEN 2.070 AND 2.270 --------------------DELBET84
  500 AM1=2.07                                                          DELBET85
      AM2=2.27                                                          DELBET86
      DB1=DBET(C(1),C(2),C(3),ALPHA,BETAV)                              DELBET87
      DB2=DBET(D(1),D(2),D(3),ALPHA,BETAV)                              DELBET88
      FACTOR=((AMCT*AMCT)-(AM1*AM1))/((AM2*AM2)-(AM1*AM1))              DELBET89
      BETA=BETA0+(DB1+(FACTOR*(DB2-DB1)))                               DELBET90
      RETURN                                                            DELBET91
C     BETA FOR MACH NUMBER BETWEEN 2.270 AND 2.550 --------------------DELBET92
  600 AM1=2.27                                                          DELBET93
      AM2=2.55                                                          DELBET94
      DB1=DBET(D(1),D(2),D(3),ALPHA,BETAV)                              DELBET95
      DB2=DBET(E(1),E(2),E(3),ALPHA,BETAV)                              DELBET96
      FACTOR=((AMCT*AMCT)-(AM1*AM1))/((AM2*AM2)-(AM1*AM1))              DELBET97
      BETA=BETA0+(DB1+(FACTOR*(DB2-DB1)))                               DELBET98
      RETURN                                                            DELBET99
      END                                                               DELBET 0
```

SUBROUTINE DBETA0:

Purpose. Subroutine DBETA0 calculates the value the NBIU true angles would have for the NBIU indicated angle of sideslip and freestream Mach number (using data fairings for) 0.0 degrees angle of attack.

Storage Required.

OCTAL WORDS	DECIMAL WORDS
266	182

Subprograms Used.

CNVRG, ABS (absolute function)

Calling Statement.

CALL DBETA0 (BETAV,AMCT,CONVRB,IFLAG,BETA0)

Calling Argument Input.

INPUT		DESCRIPTION	UNITS
β_v	BETAV	NBIU indicated angle of sideslip	deg
M	AMCT	freestream Mach number	N-D
$\Delta\beta_{con}$	CONVRB	angle-of-sideslip convergence factor	deg
	IFLAG	error flag (see Error Flag Structure, Subroutine ANGLES)	---

Calling Argument Output.

OUTPUT		DESCRIPTION	UNITS
β_0	BETA0	NBIU true angle of sideslip for the input values at 0.0 degrees angle of attack	deg
	IFLAG	error flag (see Error Flag Structure, Subroutine ANGLES)	---

Program Description. Subroutine DBETA0 calculates the NBIU true angle of sideslip for the NBIU indicated angle and freestream Mach number using data fairings for 0.0 degrees angle of attack. The fairings were done in six segments covering various Mach number ranges. All fairings were done in terms of local flow error versus true angle of sideslip and Mach number so subroutine CNVRG was called to iterate to obtain true angle of sideslip from the indicated value.

Program Listing.

```
      SUBROUTINE DBETAO(BETAV,AMCT,CONVRB,IFLAG,BETAO)
C     ******************************************************************
C
C     SUBROUTINE DBETAO DETERMINES BOOM TRUE ANGLE OF SIDESLIP GIVEN THE
C     BOOM INDICATED ANGLE OF SIDESLIP AND CORRESPONDING FREESTREAM MACH
C     NUMBER. THE SUBROUTINE IS VALID ONLY AT 0.0 DEGREES ANGLE OF
C     ATTACK.
C
C     EXTERNAL VARIABLES-
C               NAME       DESCRIPTION                           UNITS
C     INPUT   - BETAV    - BOOM INDICATED ANGLE OF SIDESLIP    - DEGREES
C               AMCT     - FREESTREAM MACH NUMBER              - *******
C               CONVRB   - ITERATION CONVERGENCE FACTOR FOR
C                          ANGLE OF SIDESLIP                   - DEGREES
C     OUTPUT  - BETAO    - BOOM TRUE ANGLE OF SIDESLIP AT 0.0
C                          DEGREES ANGLE OF ATTACK             - DEGREES
C               IFLG     - ITERATION REQUEST FLAG              - *******
C                          IFLG=3,ITERATION REQUESTED ON ANGLE
C                                 OF SIDESLIP
C               IFLAG    - ERROR FLAG                          - *******
C
C     REVISION RECORD-
C                    NAME                         DATE
C     WRITTEN BY - MARK KORSMO                     9 FEB 1978
C     REVISED BY - KEN RAWLINGS                   23 JUL 1981
C
C     ******************************************************************
      DIMENSION A(3),B(3),C(3),D(3),E(3)
      DATA IFLG/3/
C     SET VALUES OF CONSTANTS FROM CURVE FITS --------------------------
      DATA B11,B21,S11,S21      /-1.09600, +0.30297, -0.83625, -0.08829/
      DATA A                    /-.2833568E-3, .0000000E00,-.8340577E-1/
      DATA B                    /+.0000000E00,-.1520952E-1,+.1921397E00/
      DATA C                    /-.4792185E-3, .0000000E00,+.7057031E-1/
      DATA D                    /+.1791000E-2,-.3334467E-1,+.6650189E-1/
      DATA E                    /+.5989991E-3, .0000000E00,-.1840622E00/
C     DEFINE STATEMENT FUNCTION ----------------------------------------
      DBETO(P,Q,R,B)=(P*B*B*B)+(Q*B*ABS(B))+(R*B)
C     DETERMINE TRUE ANGLE OF SIDESLIP AT 0.0 DEGREES ANGLE OF ATTACK --
      IF(AMCT .LE. 1.30) GO TO 100
      IF(AMCT .LE. 1.55) GO TO 200
      IF(AMCT .LE. 1.88) GO TO 300
      IF(AMCT .LE. 2.07) GO TO 400
      IF(AMCT .LE. 2.27) GO TO 500
      GO TO 600
```

```
C       BETAO FOR MACH NUMBER LESS THAN 1.300 -------------------------DBETA046
  100   CALL CNVRG(B11,B21,S11,S21,BETAV,AMCT,CONVRB,IFLG,BETAO,IFLAG)  DBETA047
        RETURN                                                          DBETA048
C       BETAO FOR MACH NUMBER BETWEEN 1.300 AND 1.550 -----------------DBETA049
  200   AM1=1.30                                                        DBETA050
        AM2=1.55                                                        DBETA051
        CALL CNVRG(B11,B21,S11,S21,BETAV,AM1,CONVRB,IFLG,BETAO,IFLAG)   DBETA052
        DB1=BETAO-BETAV                                                 DBETA053
        DB2=DBETO(A(1),A(2),A(3),BETAV)                                 DBETA054
        FACTOR=((AMCT*AMCT)-(AM1*AM1))/((AM2*AM2)-(AM1*AM1))            DBETA055
        BETAO=BETAV+(DB1+(FACTOR*(DB2-DB1)))                            DBETA056
        RETURN                                                          DBETA057
C       BETAO FOR MACH NUMBER BETWEEN 1.550 AND 1.880 -----------------DBETA058
  300   AM1=1.55                                                        DBETA059
        AM2=1.88                                                        DBETA060
        DB1=DBETO(A(1),A(2),A(3),BETAV)                                 DBETA061
        DB2=DBETO(B(1),B(2),B(3),BETAV)                                 DBETA062
        FACTOR=((AMCT*AMCT)-(AM1*AM1))/((AM2*AM2)-(AM1*AM1))            DBETA063
        BETAO=BETAV+(DB1+(FACTOR*(DB2-DB1)))                            DBETA064
        RETURN                                                          DBETA065
C       BETAO FOR MACH NUMBER BETWEEN 1.880 AND 2.070 -----------------DBETA066
  400   AM1=1.88                                                        DBETA067
        AM2=2.07                                                        DBETA068
        DB1=DBETO(B(1),B(2),B(3),BETAV)                                 DBETA069
        DB2=DBETO(C(1),C(2),C(3),BETAV)                                 DBETA070
        FACTOR=((AMCT*AMCT)-(AM1*AM1))/((AM2*AM2)-(AM1*AM1))            DBETA071
        BETAO=BETAV+(DB1+(FACTOR*(DB2-DB1)))                            DBETA072
        RETURN                                                          DBETA073
C       BETAO FOR MACH NUMBER BETWEEN 2.070 AND 2.270 -----------------DBETA074
  500   AM1=2.07                                                        DBETA075
        AM2=2.27                                                        DBETA076
        DB1=DBETO(C(1),C(2),C(3),BETAV)                                 DBETA077
        DB2=DBETO(D(1),D(2),D(3),BETAV)                                 DBETA078
        FACTOR=((AMCT*AMCT)-(AM1*AM1))/((AM2*AM2)-(AM1*AM1))            DBETA079
        BETAO=BETAV+(DB1+(FACTOR*(DB2-DB1)))                            DBETA080
        RETURN                                                          DBETA081
C       BETAO FOR MACH NUMBER BETWEEN 2.270 AND 2.550 -----------------DBETA082
  600   AM1=2.27                                                        DBETA083
        AM2=2.55                                                        DBETA084
        DB1=DBETO(D(1),D(2),D(3),BETAV)                                 DBETA085
        DB2=DBETO(E(1),E(2),E(3),BETAV)                                 DBETA086
        FACTOR=((AMCT*AMCT)-(AM1*AM1))/((AM2*AM2)-(AM1*AM1))            DBETA087
        BETAO=BETAV+(DB1+(FACTOR*(DB2-DB1)))                            DBETA088
        RETURN                                                          DBETA089
        END                                                             DBETA090
```

SUBROUTINE CNVRG:

Purpose. Subroutine CNVRG calculates the true values of ei⁻ ·r angle of attack or angle of sideslip based on the indicated values, freestream Mach number, and constants determined from data fitting. The iteration performed by CNVRG is discussed in the body of this memorandum and within the computer code.

Storage Required.

OCTAL WORDS	DECIMAL WORDS
117	79

Subprograms Used.

SIN (sine function), ABS (absolute function)

Calling Statement.

CALL CNVRG (B1,B2,S1,S2,TAUV,AMCT,CONVR,IFLG,TAU,IFLAG)

Calling Argument Input.

	INPUT	DESCRIPTION	UNITS
	B1	constant in the intercept equation	deg
	B2	constant in the intercept equation	deg
	S1	constant in the slope equation	deg
	S2	constant in the slope equation	deg
	TAUV	indicated angle	deg
M	AMCT	freestream Mach number	N-D
	CONVR	iteration convergence factor	deg
	IFLG	iteration request flag IFLG = 2, angle of attack IFLG = 3, angle of sideslip	---

Calling Argument Output.

OUTPUT	DESCRIPTION	UNITS
TAU	true angle	deg
IFLAG	error flag (see Error Flag Structure, Subroutine ANGLES)	---

Program Description. Subroutine CNVRG initially sets the true value of the desired angle to the indicated value and calculates a delta value based on the entered constants from curve fits. The subroutine iterates until two consecutive values of the delta value are less than or equal to the iteration convergence factor. However, if more than 20 iterations are required, the error flag is set and the true value is returned as the value from the last iteration.

Program Listing.

```
      SUBROUTINE CNVRG(B1,B2,S1,S2,TAUV,AMCT,CONVR,IFLG,TAU,IFLAG)
C     *****************************************************************
C
C     SUBROUTINE CNVRG DETERMINES THE VALUE OF A TRUE ANGLE FROM ITS
C     INDICATED VALUE AND CONSTANTS DETERMINED FROM CURVE FITS. THE TRUE
C     ANGLE IS RELATED TO THE INDICATED VALUE BY
C
C              TAU = TAUV + DELTAU
C
C     THE VALUE OF DELTAU VARIES LINEARILY WITH MACH NUMBER SQUARED SO
C
C              DELTAU = INTERCEPT + (SLOPE*AMCT*AMCT)
C
C     HOWEVER, BOTH THE SLOPE AND INTERCEPT VARY WITH THE TRUE ANGLE SO
C     THAT
C                                                 2
C              INTERCEPT = B1*SIN(2*TAU) + B2*SIN (2*TAU)
C
C                                                 2
C              SLOPE     = S1*SIN(2*TAU) + S2*SIN (2*TAU)
C
C     THIS SYSTEM OF EQUATIONS IS SOLVED USING A CONVERGENT ITERATION
C     TECHNIQUE IN BOTH THE ANGLE OF ATTACK AND ANGLE OF SIDESLIP
C     CALCULATIONS.
C
C     EXTERNAL VARIABLES-
C              NAME      DESCRIPTION                           UNITS
C     INPUT  - B1      - CONSTANT IN THE INTERCEPT EQUATION  - DEGREES
C              B2      - CONSTANT IN THE INTERCEPT EQUATION  - DEGREES
C              S1      - CONSTANT IN THE SLOPE EQUATION      - DEGREES
C              S2      - CONSTANT IN THE SLOPE EQUATION      - DEGREES
C              TAUV    - INDICATED ANGLE                     - DEGREES
C              AMCT    - FREESTREAM MACH NUMBER              - *******
C              CONVR   - ITERATION CONVERGENCE FACTOR
C              IFLG    - ITERATION REQUEST FLAG              - *******
C                        IFLG=2,ITERATION REQUESTED ON ANGLE
C                               OF ATTACK
C                        IFLG=3,ITERATION REQUESTED ON ANGLE
C                               OF SIDESLIP
```

```
C     OUTPUT - TAU      - TRUE ANGLE                                - DEGREES  CNVRG 40
C              IFLAG    - ERROR FLAG                                - *******  CNVRG 41
C                         IFLAG=2,CNVRG INTERNAL CONVERGENCE                   CNVRG 42
C                                ON ANGLE OF ATTACK FAILED                     CNVRG 43
C                         IFLAG=3,CNVRG INTERNAL CONVERGENCE                   CNVRG 44
C                                ON ANGLE OF SIDESLIP FAILED                   CNVRG 45
C                         IFLAG=5,CNVRG INTERNAL CONVERGENCE                   CNVRG 46
C                                ON ANGLE OF ATTACK AND                        CNVRG 47
C                                ON ANGLE OF SIDESLIP FAILED                   CNVRG 48
C                                                                              CNVRG 49
C     REVISION RECORD-                                                         CNVRG 50
C                  NAME                              DATE                      CNVRG 51
C     WRITTEN BY - MARK KORSMO                        9 FEB 1978               CNVRG 52
C     REVISED BY - KEN RAWLINGS                      23 JUL 1981               CNVRG 53
C                                                                              CNVRG 54
C     *****************************************************************CNVRG 55
      REAL INTER                                                               CNVRG 56
C     DEFINE STATEMENT FUNCTIONS ------------------------------------------CNVRG 57
      SINE2A(A)=SIN(2.*A/57.296)                                               CNVRG 58
      SIN2SQ(A)=SIN(2.*A/57.296)*SIN(ABS(2.*A/57.296))                         CNVRG 59
C     INITIALIZE ITERATION VARIABLES --------------------------------------CNVRG 60
      TAU=TAUV                                                                 CNVRG 61
      DTAULI=0.0                                                               CNVRG 62
C     ITERATE TO OBTAIN TRUE ANGLE ----------------------------------------CNVRG 63
      DO 100 I=1,20                                                            CNVRG 64
      INTER=B1*SINE2A(TAU)+B2*SIN2SQ(TAU)                                      CNVRG 65
      SLOPE=S1*SINE2A(TAU)+S2*SIN2SQ(TAU)                                      CNVRG 66
      DELTAU = INTER +  (SLOPE*AMCT*AMCT)                                      CNVRG 67
      TAU=TAUV + DELTAU                                                        CNVRG 68
      IF(ABS(DELTAU-DTAULI)  .LE.  CONVR) RETURN                               CNVRG 69
      DTAULI=DELTAU                                                            CNVRG 70
  100 CONTINUE                                                                 CNVRG 71
C     SET FLAG DENOTING FAILURE OF ITERATION TO CONVERGE ------------------CNVRG 72
      IF((IFLAG   .EQ.   IFLG) .OR. (IFLAG .EQ. 5)) RETURN                     CNVRG 73
      IF(((IFLAG+IFLG) .EQ. 5) .OR. (IFLAG .EQ. 0)) IFLAG=IFLAG+IFLG           CNVRG 74
      RETURN                                                                   CNVRG 75
      END                                                                      CNVRG 76
```

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